Operation and Maintenance Manual
PEM Fuel Cell Test Station

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Foreword

The Schatz Energy Research Center ("Schatz" or "SERC") provides this manual to assist researchers in the operation and maintenance of the Schatz PEM Fuel Cell Test Station. System operators should read this manual carefully, with special attention to the chapter on safety, before operating or performing maintenance on any part of the test station.

This manual is not intended to provide complete operating instructions for the system. Operators should also read the component operating manuals (found in the binder that makes up Appendix B of this manual) and complete the system operator training session before running the system. The system should only be operated by adequately trained, authorized personnel.

SERC assumes no liability for any harm or injury resulting from the proper or improper use of the fuel cell test station or this manual. In the event that test station users encounter a problem with the test station they are unable to resolve using this manual and the test station component manuals, they should shut down the test station and contact Schatz staff immediately by phoning (707) 826-4345, faxing a description of the problem to (707) 826-4347, or emailing a description of the problem to serc@humboldt.edu.

Table of Contents

List of Tables vi
List of Acronyms vii
Preface viii
Document Layout viii
Chapter I: Test Station Description 1
A. Air System 2
B. Hydrogen System 3
C. Water Circulation System 4
D. Electrical System, Electronic Load, and UPS 5
E. Monitoring and Control Hardware 6
F. Test Station Software 7
G. Safety Control System 8
1. High Level (Software Independent) Faults 9
2. Low Level (Software Initiated) Faults 9
3. Normal Shutdown 9
4. Emergency Shutdown 10
Chapter II: System Requirements 11
A. Test Station Requirements 11
1. Oil-Free Compressed Air 11
2. Hydrogen Supply and Venting 11
3. Water Supply 11
4. Water Drainage 12
5. Power Supply 12
B. Fuel Cell Requirements 12
1. Air Supply 12
2. Hydrogen Supply 12
3. Water Circulation/Temperature Control 12
Chapter III: Test Station Hardware Operation 14
A. Fuel Cell Stack Connection 14
B. Low Pressure Regulator Adjustment 16
C. Hydrogen Cylinder Initial Set-up and Exchange 17
D. Switching Air Mass Flow Controllers 18
E. Air Blower Operation 18
F. Test Station Power 19
Chapter IV: Test Station Software 21
A. Software Description 21
1. Front Panel 21
2. Block Diagram 38
B. Startup and Shutdown 42
C. Modifying Software 47
1. Adding a Blower 47
2. Switching Air Mass Flow Controllers 48
3. Manipulating Data Files 48
4. Connecting a New Transducer 50

5. Modifying the Graphs 51
Chapter V: Troubleshooting 53
A. High-Level Faults 53
1. Hydrogen Leaks 53
2. Smoke Alarms 53
3. Fan Alarm 54
B. Clearing Safety Faults 54
C. Software Debugging 54
D. Low-Level Faults 55
E. Fuel Cell Faults 58
1. Troubleshooting 58
2. Cross Leak Check 59
Chapter VI: System Maintenance 61
A. Air, Hydrogen and Water Systems Maintenance 61
1. Visual Inspection 61
2. Pressure Relief Devices 61
3. Leak Checks 62
4. Valve and Regulator Cross-Leak Checks 63
5. Deionization Cartridge Changeout 63
6. Hydrogen Filter Inspection 64
7. Hydrogen Vent Line Purging 64
B. Safety System 64
1. Smoke Alarms 64
2. Ventilation Flow Transducer 65
3. Hydrogen Detector 65
C. Transducer Calibrations 66
D. Control and Monitoring Hardware 66
1. Check Integrity and Condition of Visible Wiring 66
2. Keep Components Clean 66
3. Uninterruptible Power Supply (UPS) 67
Chapter VII: Safety 68
A. Safety Orientation 68
B. Test Station Safety Features 68
1. Properties of Hydrogen Gas 69
2. Handling Compressed Gases 72
C. Safety Equipment and Guidelines 75
1. Fire extinguishers 75
2. Hydrogen Gas Detection 76
3. Hydrogen Flame Detection 76
4. Safety Glasses 76
5. Hearing Protection 76
6. Fire Blanket 77
D. Hazard Identification and Response 77
1. High Pressure Hazards 77
2. Fire and Combustion Hazards 78
3. Electric Shock Hazards 79

E. Safety Policies 80
Tagout/Lockout Procedure 81
F. Material Safety Data Sheets (MSDS) 81
G. Additional Informational Resources 82

Appendices

Appendix A: System Specifications and Drawings
A1: Test Station Specifications
A2: DAQ Channel I/O List
A3: Symbolic Subsystem Drawings
Appendix B: Component Manuals and Spec Sheets *(included as separate binder)*
B1: Air System Components
B2: Hydrogen System Components
B3: Water Circulation System Components
B4: Electrical System Components
B5: Monitoring and Control System Components
B6: Safety System Components
Appendix C: Quick Reference Sheets for Operating Procedures
Appendix D: Material Safety Data Sheet

List of Figures

Figure I-1. Photo of Test Station Showing Major Components 1
Figure I-5. Electronics Cabinet 6
Figure I-6. DAQ Panel 7
Figure I-7. Software Front Panel 8
Figure III-1. Location of System Connections 14
Figure III-2. Air, Hydrogen and Water Supply and Exhaust Lines 15
Figure III-3. Rear View of Stack Showing VTaps 16
Figure III-4. Front Panel of the Safety Tray 19
Figure IV-1. Software Front Panel 22
Figure IV-2. Front Panel Air Controls, Indicators and Settings 23
Figure IV-3. Front Panel Hydrogen Controls, Indicators and Settings 25
Figure IV-4. Front Panel Cooling Controls, Indicators and Settings 26
Figure IV-5. Front Panel Fuel Cell Indicators 28
Figure IV-6. Front Panel Safety Controls and Settings 30
Figure IV-7. Front Panel Load Settings 31
Figure IV-8. Front Panel Load Settings When Pulsing the Load 32
Figure IV-9. Front Panel Load Settings When Running an IV Curve 33
Figure IV-10. Front Panel File Settings 34
Figure IV-11. Front Panel Test Settings 35
Figure IV-12. Front Panel Cell Voltage Plots 36
Figure IV-13. Front Panel Additional Channels Display 37
Figure IV-14. Error Status display 38
Figure IV-15. Startup and Subtask Section of the Block Diagram 39
Figure IV-16. Display and Shutdown Section of the Block Diagram 41
Figure IV-17. Dialog for choosing a stack to test 44
Figure IV-18. Dialog for setting the stack parameters 44
Figure IV-17. Data File Configuration Dialog 49
Figure IV-18. Dialog for Selecting the Data File Contents 50
Figure IV-19. Modifying the IV Curve Graph 51

List of Tables

Table IV-1. Air Subsystem Controls, Indicators, and Settings 23
Table IV-2. Hydrogen Subsystem Controls, Indicators, and Settings 24
Table IV-3. Cooling Subsystem Controls, Indicators, and Settings 26
Table IV-4. Fuel Cell Indicators 28
Table IV-5. Safety Controls and Settings 29
Table IV-6. Load Settings 30
Table IV-7. File Settings 34
Table IV-8. Test Settings 35
Table IV-9. Normal Values for Test Station Operating Variables 46
Table V-1. Troubleshooting a Low-Level Fault 56
Table V-2. Troubleshooting Fuel Cell Stack Failures 58
Table VI-1. Pressure Relief Valve Setpoints 61
Table VII-1. Some Physical Properties of Hydrogen and Methane 70

List of Acronyms

AC	alternating current
BP	back pressure
CGA	Compressed Gas Association
DAQ	data acquisition
DC	direct current
DI	deionized
DOT	U.S. Department of Transportation
FC	fuel cell
gpm	gallons per minute
H_2	hydrogen
H_2O	water
in. WC	inches of water column
I/O	input/output
IV	current-voltage (as in IV curve or polarization curve for a fuel cell)
lpm	liters per minute
MEA	membrane electrode assembly
MFC	mass flow controller
NFPA	National Fire Protection Association
O_2	oxygen gas
PEM	proton exchange membrane
PRD	pressure relief device
PRV	pressure relief valve
psi	pounds per square inch
psig	pounds per square inch (gauge)
SERC	Schatz Energy Research Center
sl	standard liter (at 0°C, 1 atm)
slm	standard liters per minute
SSR	solid state relay
TFC	fuel cell operating temperature
UPS	uninterruptible power supply
V	voltage
VAC	volts (alternating current)
VDC	volts (direct current)
VTaps	custom cell voltage probes
µS	microsiemens
ΔP	pressure differential

Preface

This manual was prepared by Schatz Energy Research Center (SERC) staff as a guide to operation and maintenance of the PEM Fuel Cell Test Station. Users of this document will include personnel trained and authorized to use the test station system.

Document Layout

This manual begins with an overall description of the test station in Chapter I. System requirements are explained in Chapter II. Chapter III guides the user step-by-step through operation of the test station hardware. Chapter IV deals with the test station software. Chapter V is dedicated to system troubleshooting. Chapter VI addresses system maintenance, with emphasis on the use of periodic checklists. Chapter VII discusses safety, including hazard identification and emergency response procedures. Appendix A includes test station specifications and drawings of the systems that make up the test station. Appendix B (included as a separate binder) holds manufacturers' product manuals and specification sheets. Appendix C consists of quick-reference operating instruction sheets. Appendix D is a material safety data sheet (MSDS) for hydrogen.

Due to the presence of high pressure, flammable hydrogen gas and various high and medium voltage electrical equipment, the primary potential hazards associated with the test station are high-pressure gas accidents, fire, and electric shock. Accordingly, ALL operation and maintenance procedures performed on the fuel cell test station should be performed with the utmost care. However, some procedures described in this manual are particularly critical and could result in serious personal injury and/or damage to the test station if performed incorrectly. These procedures are marked with an exclamation mark in the margin as shown at left and are marked "Warning," "Caution," "Important," or "Note".

Chapter I: Test Station Description

The purpose of this chapter is to provide an overview of the PEM Fuel Cell Test Station (hereinafter simply referred to as the "test station") and its major components. The test station is designed to allow researchers to test and evaluate proton exchange membrane (PEM) fuel cell stacks. SERC has provided a 24-cell, 300 cm^2 PEM fuel cell stack along with the test station. A photo of the system showing placement of major components is shown in Figure I-1.

The Test Station consists of seven integrated systems, all mounted on a standard workbench and an attached Superstrut® frame. The systems include:

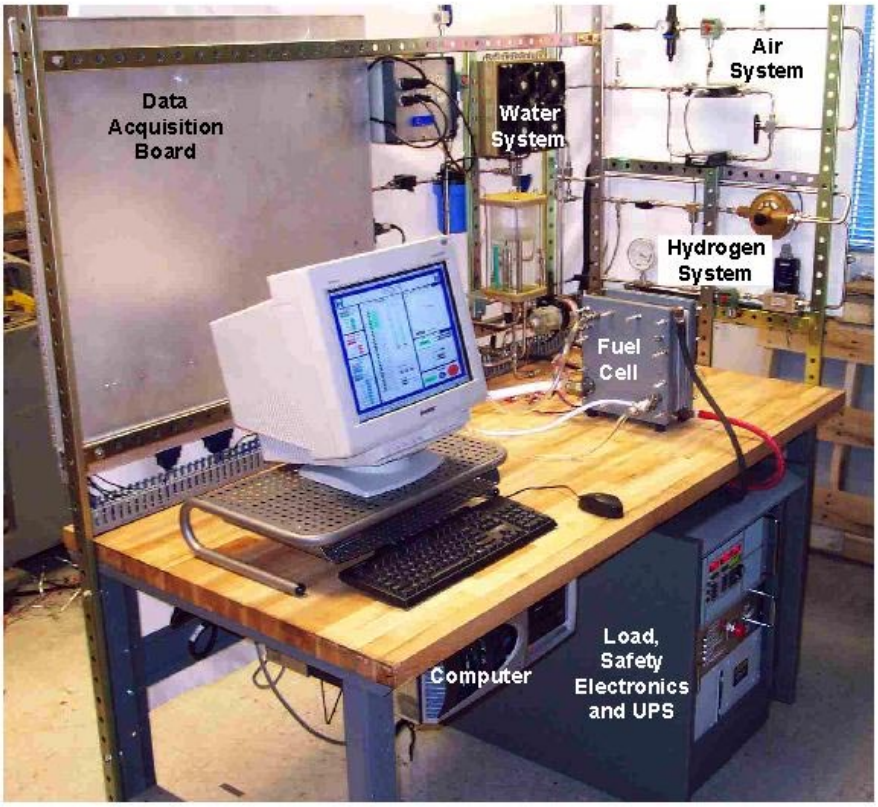


Figure I-1. Photo of Test Station Showing Major Components

- **Air System.** The oxygen in air acts as a reactant with the hydrogen in the fuel cell, producing water and releasing electrical energy. This system provides air from a blower or mass flow controller to the stack.
- **Hydrogen System.** Hydrogen is the fuel that powers PEM fuel cells. The hydrogen system stores hydrogen in high-pressure cylinders and reduces the pressure to a level appropriate for delivery to the fuel cell stack.
- **Water Circulation System.** Water is used as a heat transport medium in the test station to either heat or cool the stack using electric resistance heating and a heat

exchanger. Water also circulates through the humidification section of the fuel cell stack to humidify the incoming air stream.

- **Electrical System.** AC and DC electric power are used to operate the test station's instrumentation. The electrical system also includes an electronic load used to absorb and control power produced by the fuel cell stack and an uninterruptible power supply (UPS) used to keep the test station running through utility brownouts or brief blackouts.
- **Monitoring and Control Hardware.** A standard computer combined with analog and digital data acquisition hardware is used to monitor and control the fuel cell subsystems.
- **Test Station Software.** Test station operation is controlled using LabVIEW™ software, which also provides an interface between the operator and the test station's monitoring and control hardware.
- **Safety Control System.** A number of hardware- and software-controlled safety shutdowns ensure safe operation of the test station.

A detailed description of each system is given below along with labeled photos where appropriate. Detailed specifications for the test station and schematic drawings of the individual systems are included in Appendix A. Specification sheets and user manuals for individual test station components are provided in Appendix B (included as a separate binder).

A. Air System

The air system plumbing is located just above the hydrogen system plumbing on the Superstrut® frame above the right hand end of the bench (see Figure I-1). Dry, oil-free, compressed air is supplied to the inlet isolation valve of the air system located at the top right corner of the bench. Air system plumbing is 3/8" stainless steel tubing and rated to 3300 psig. A pressure regulator with a pressure gauge and coalescer reduces the pressure to approximately 30 psig, provides pressure indication and removes water from the air stream. A supply solenoid valve allows automatic shutoff of airflow through the system, and a medium pressure relief valve (set at 55 psig) protects downstream components from overpressure. The air system is equipped with both low range (0-20 slm) and high range (0-200 slm) mass flow controllers. The procedure to switch controllers is simple and is provided in Chapter III. Other components include a pressure gauge, a pressure transducer, and a low pressure relief valve (set at 150 in. WC). See Figure I-2 for a photo of the air delivery plumbing.

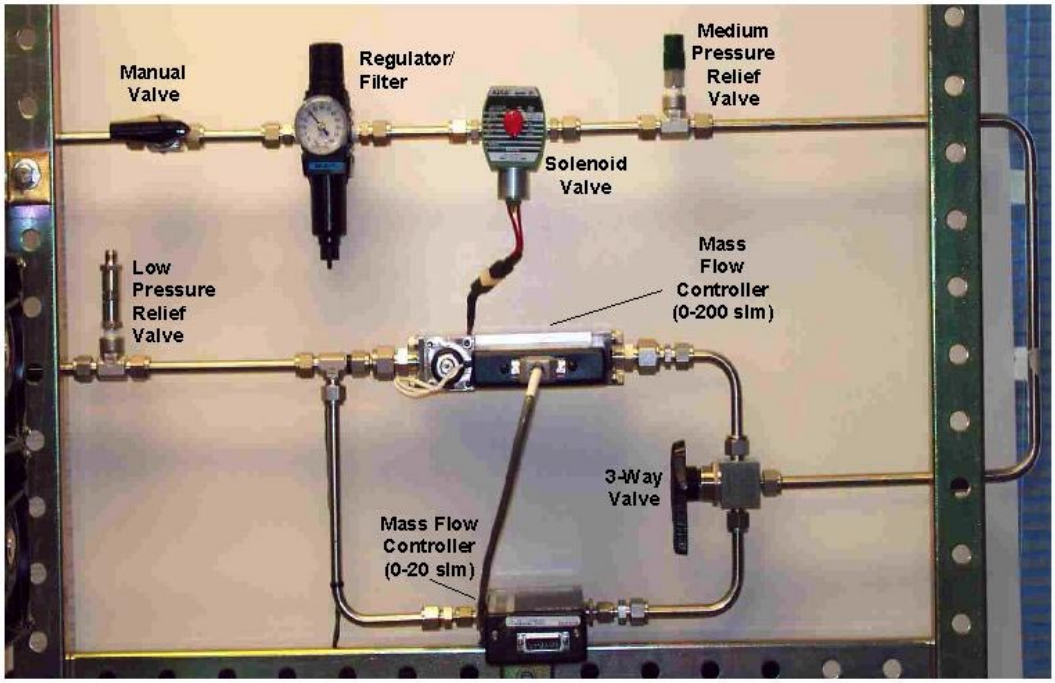


Figure I-2. Air System

B. Hydrogen System

The hydrogen system supplies hydrogen gas from high-pressure cylinders to the fuel cell stack, reducing the gas pressure to an appropriate level along the way. Hydrogen system plumbing is located just above the right hand end of the bench. A hydrogen cylinder rack, adjacent to the test station bench top, is designed to hold Compressed Gas Association-approved Size 44 cylinders. Only one cylinder of hydrogen will be in service at a time.

The high-pressure gas from the in-service cylinder enters a two-stage regulator set to deliver gas at 40-100 psig. The hydrogen gas then passes via a flex hose to the hydrogen delivery plumbing mounted to the Superstrut®. The hydrogen plumbing is also 3/8" stainless steel tubing rated to 3300 psig. A vent valve and a supply valve provide depressurization and isolation capability when performing system maintenance or exchanging hydrogen cylinders.

Hydrogen gas pressure is next reduced to 0.5 to 5.0 psig by a single-stage low-pressure regulator. A pressure relief valve (set at 150 psig) is located upstream of the low-pressure regulator and protects the regulator from overpressure. Another pressure relief valve (set at 9 psig) is built into the regulator and provides downstream overpressure protection for the fuel cell. An in-line 7-micron filter removes debris from the gas stream to protect downstream components and the fuel cell. Other components include a mass flow transducer to monitor gas flow and a supply solenoid valve that allows automatic shutoff of the hydrogen gas supply to the fuel cell. A pressure gauge and a pressure transducer provide local and remote indication of fuel cell pressure.

When a fuel cell is running on the test station, periodic purges of the hydrogen gas remove water accumulated on the anode side of each cell in the stack. The purge section of the hydrogen system is located on the outlet of the fuel cell and includes a purge solenoid valve, a manual bypass valve, and a purge drum. The purge drum is mounted to the back right leg of the test bench and has a manual drain valve and vent line. During a purge, hydrogen gas flow increases rapidly and pushes water from the fuel cell through the purge solenoid valve and into the purge drum. Liquid water separates from the gas stream and hydrogen is vented through the low pressure vent line. The water accumulates in the drum and should be manually drained to the fuel trench when necessary.

See Figure I-3 for a photo of the hydrogen delivery plumbing.

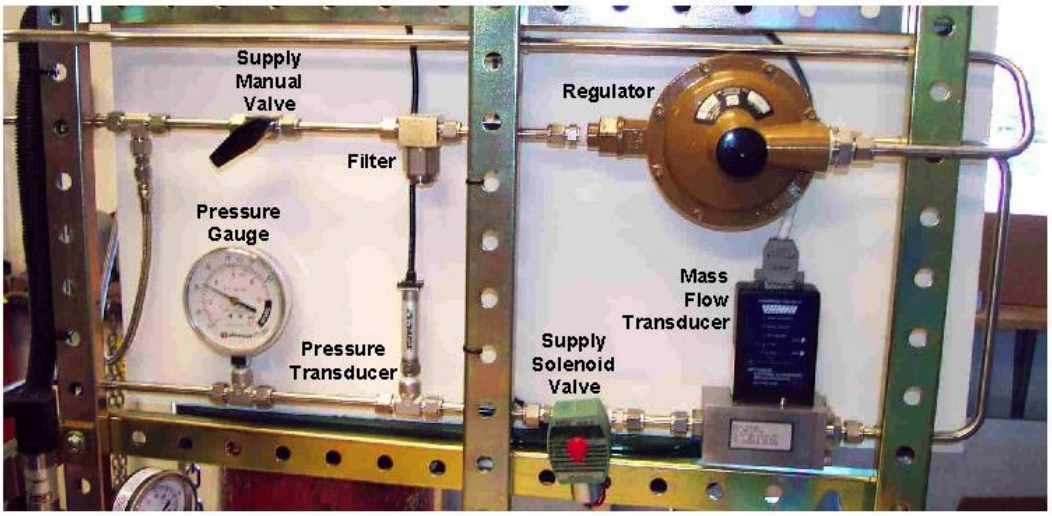


Figure I-3. Hydrogen System

C. Water Circulation System

Deionized (DI) water is connected to the water system at the inlet to a manual valve at the top center of the test bench. The addition of water to the water circulation system is accomplished using an automatic solenoid valve that is triggered by a float switch in the water reservoir. Water is circulated in a closed loop system to control the temperature of the water entering the humidification section of the fuel cell stack. When in the heating mode, cartridge heaters placed in the water reservoir and heat tape wrapped around a section of stainless steel tubing are used to heat the DI water before it enters the fuel cell stack. When in the cooling mode, fans mounted to the heat exchanger are controlled to maintain the desired stack temperature. A water flow meter senses water flow, and the flow rate can be manually throttled with a valve located upstream of the heat exchanger. A water conductivity sensor provides water quality indication. Ions introduced by the system are removed by a cartridge deionizing filter located upstream of the fuel cell. A pressure relief valve set at 3 psig (83 in. WC) protects the fuel cell from potential water system overpressure.

See Figure I-4 for a photo of the water plumbing.

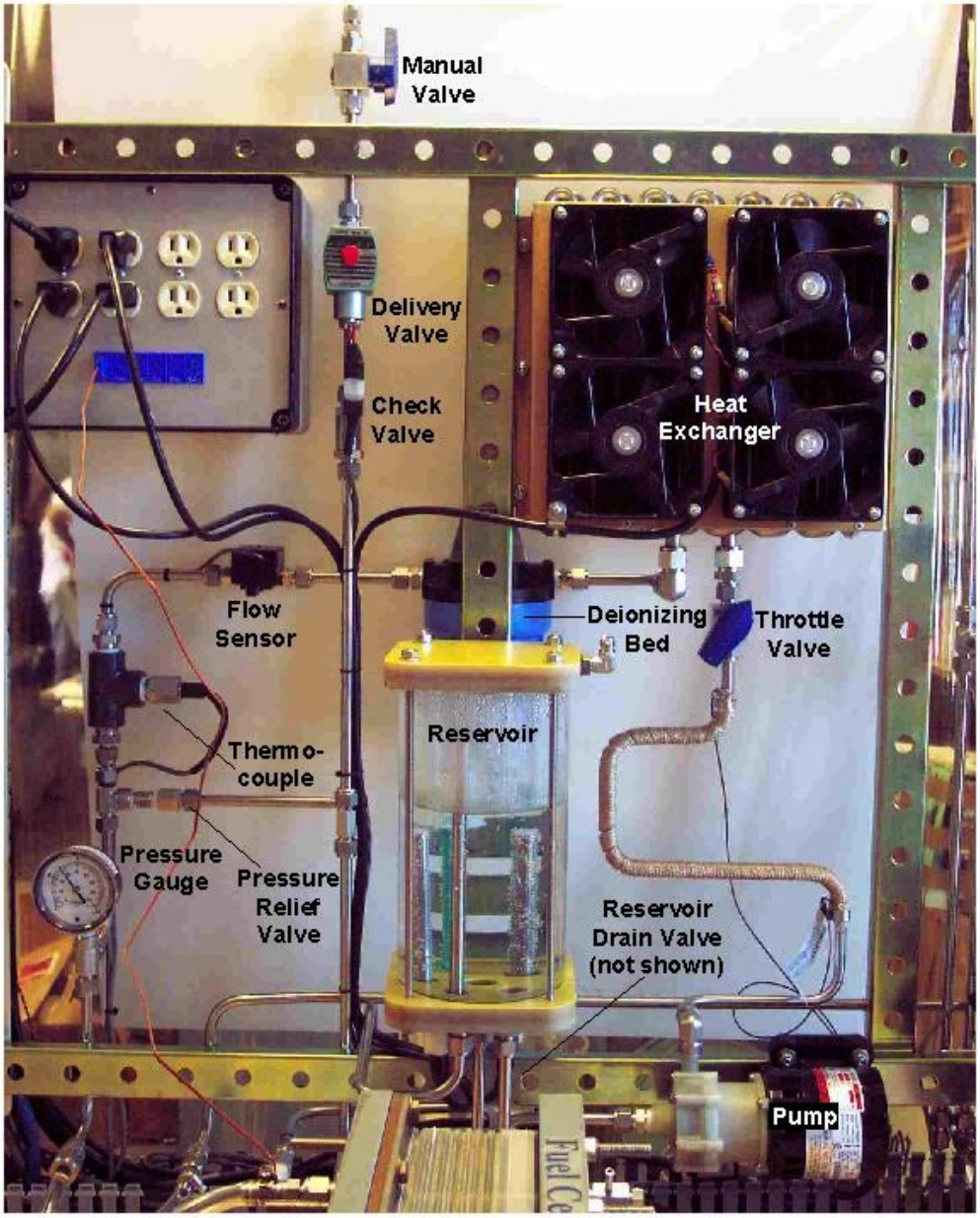


Figure I-4. Water System

D. Electrical System, Electronic Load, and UPS

Power is provided to the test bench from a 30A, 120 VAC circuit hardwired into the junction box adjacent to the electrical panel on the wall behind the test station. Power is routed through a TrippLite SmartPro 3000 uninterruptible power supply unit with a 2.4 kW capacity. The UPS, mounted in the electronics cabinet, is used to prevent testing interruptions due to power fluctuations or outages.

One 15A, 120 VAC circuit (circuit #1) is connected from the UPS to the Safety Tray. This circuit is used to supply 120 VAC, 24 VDC, 5 VDC, and ±15 VDC to the test station hardware. Power from this circuit is disconnected under some safety fault conditions (see section G. Safety Control System in this chapter for further information).

A second 15A, 120VAC circuit (circuit #2) from the UPS provides power directly to the electronic load and the control computer and computer monitor. The fuel cell stack is connected to the DynaLoad RBL488 electronic load, which is capable of dissipating up to 4kW of power generated by a fuel cell stack. The load is mounted in the top of the electronics cabinet beneath the test bench. Figure I-5 contains a photograph of the electronics cabinet.

Figure I-5. Electronics Cabinet

E. Monitoring and Control Hardware

An off-the-shelf personal computer, equipped with DAQ hardware and LabVIEW™ software, is used to monitor and control the test station. There are two parts to the data acquisition and signal conditioning system, one analog and one digital. Analog signals are routed through 5B Series backplanes and optically isolated 5B Series signal conditioning modules to two different DAQ boards in the computer. Digital signals are conditioned using an SSR backplane with optically isolated solid-state relay modules and a third DAQ board in the computer. Figure I-6 shows the monitoring and control

hardware mounted to the DAQ panel, with the labels and dashed lines indicating groupings of major components.

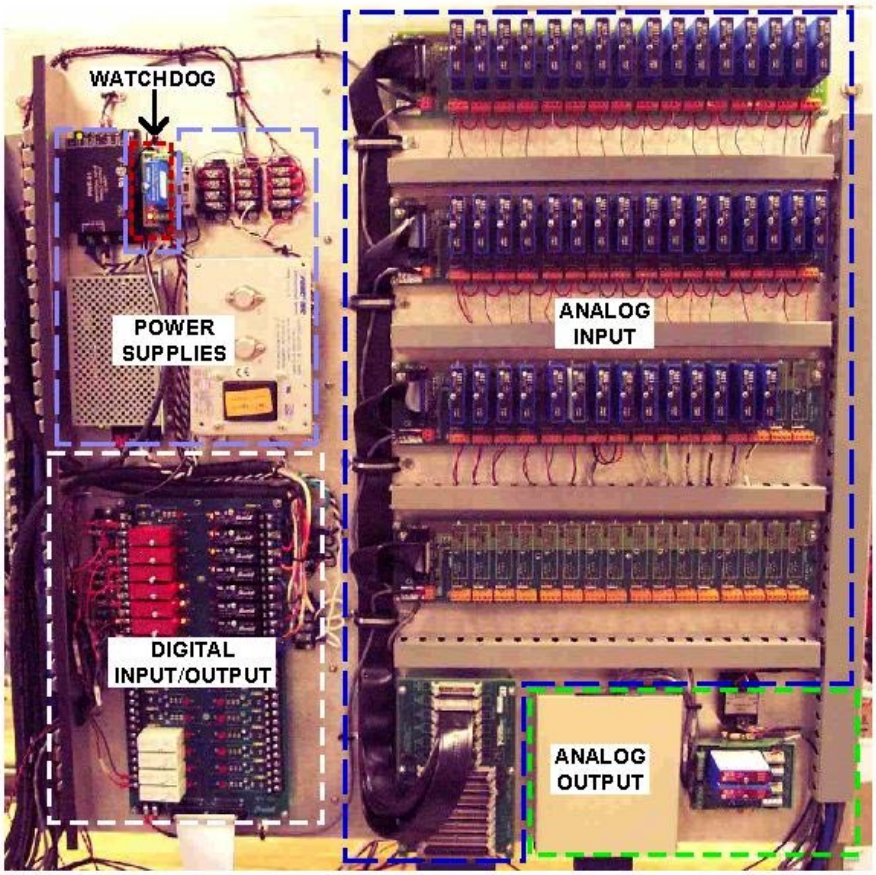


Figure I-6. DAQ Panel

The electronic load is controlled using an IEEE 488.2 (GPIB) controller board in the computer and a LabVIEW™ driver provided by DynaLoad.

F. Test Station Software

LabVIEW™, produced by National Instruments Corporation, is the programming language used to write the software that controls and monitors the test station. In order to operate, maintain and modify the test station software, it is necessary to have some understanding of the LabVIEW™ programming environment.

LabVIEW™ programmers interact with two different interfaces, namely the front panel and the block diagram. The front panel is the operator interface used to control and monitor the test station. A hardware state, configurable parameter, or safety condition can be manipulated using the controls on the front panel, and physical phenomena are measured and displayed using indicators and graphs on the front panel. The controls and indicators are organized by subsystem and arranged by color. Figure I-7 includes a screen

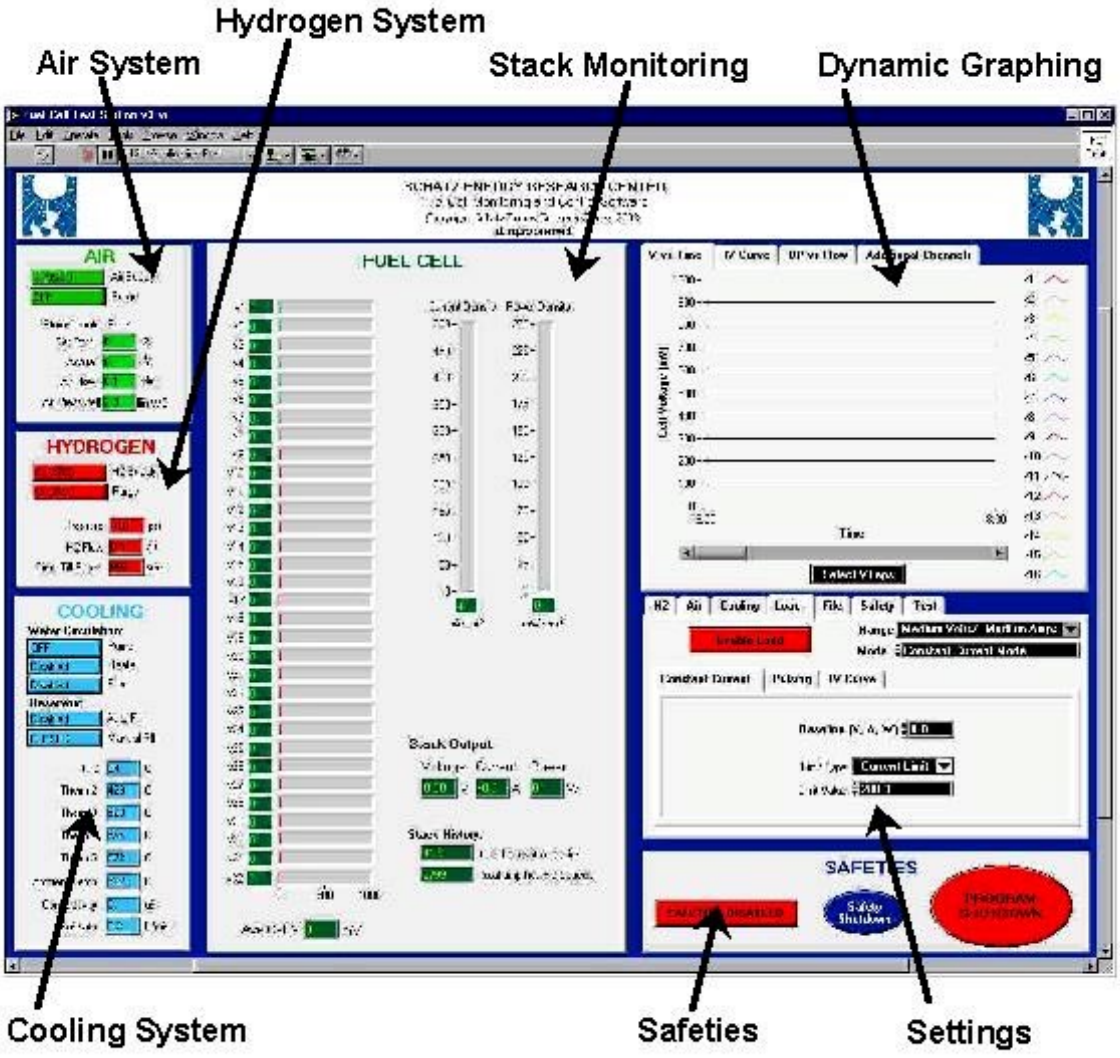


Figure I-7. Software Front Panel

shot of the test station software front panel along with the location of the controls and indicators for each subsystem.

The block diagram is a graphical representation of the control software. It is the interface used to write and modify the control logic. The only time test station users should access and make changes to the block diagram is if they want to modify the test station control software. See Sections IV.A.2 (“Block Diagram”) and IV.C (“Modifying Software”).

G. Safety Control System

There are two different types of safeties on the test station: high-level/software independent safeties (smoke alarms, H_2 detector, and ventilation fan alarm) and low level/software initiated safeties (low cell voltage, high fuel cell temperature, etc.) There

are also two different types of test station shutdowns: emergency shutdown and normal shutdown. The test station is designed to be intrinsically safe, i.e. the system components have been selected so that if power is lost for any reason, all contactors, solenoid valves, and relays will revert to a safe condition.

1. High Level (Software Independent) Faults

Faults that could create a hazardous condition if the test station were to continue operating are treated as high level faults. Power is supplied to the test station control system via circuit #1 (15 A, 120 VAC) on the UPS. This power is supplied to the 5 VDC, 24 VDC, and ±15 VDC power supplies, which in turn provide power to the transducers, relays , solenoids and other components on the test station. This AC circuit also provides switched AC power to the test station. The 120 VAC power from circuit #1 is controlled by the high level safety system. If the EMERGENCY STOP button is pressed or a high level safety alarm is activated (H2 detector, smoke alarm, vent alarm), power from this circuit will be disconnected and all contactors, solenoid valves, relays, and other test station components will revert to a safe, unpowered state.

In addition, AC power supplied to the 5 VDC and 24 VDC power supplies is routed through a watchdog timer relay. This watchdog timer is used to make sure that the backplanes and test station components (solenoid valves, relays, etc.) are only powered when the test station is running. Consequently, the LabVIEW™ program must be running (and toggling the watchdog at least every 2 seconds using a digital output signal) in order to keep the watchdog relay closed. A BACKPLANE START button is used to temporarily bypass the watchdog timer and supply power to the backplanes at startup. Once the BACKPLANE START button is released, the LabVIEW™ program continues to toggle the watchdog. Should the computer freeze, the watchdog will no longer be toggled and both the 24VDC and 5 VDC power will be lost.

The SAFETY ENABLE allows the high-level faults to be latched. Should a high-level fault occur, power to all of the power supplies will not be supplied again until someone manually resets the fault. To reset the fault, the SAFETY ENABLE button must be pressed and the fault condition must no longer be present.

2. Low Level (Software Initiated) Faults

The software handles all low-level faults. The test station operator can select whether a low-level fault is enabled and the threshold for triggering the fault in the SAFETY SETTINGS (see section IV.A.1). If a low-level fault occurs, the control system opens individual solid state relays on the digital backplane, thereby placing all hardware in a safe state (solenoid valves closed, contactors opened, etc.) The LabVIEW™ program continues to iterate and toggle the watchdog timer.

3. Normal Shutdown

During a normal shutdown, due to either a high level fault, low level fault, or deliberate stopping of the LabVIEW™ program (program shutdown button on the front panel is pressed), the watchdog timer will no longer be toggled, and AC power to the 24 VDC and

5 VDC power supplies will be disconnected. AC power will still be supplied to the ±15VDC power supply during and after normal shutdowns.

4. Emergency Shutdown

Should an emergency arise, depressing the EMERGENCY STOP button (on the front panel of the electronics cabinet beneath the bench) will shut off all power supplied to the safety tray. Alternatively, if the area around the test station becomes hazardous, personnel should leave the area and disconnect power to the test station by tripping the circuit breaker at the main electrical service panel. In either case, the electronic load and computer will continue to receive AC power via the UPS.

Chapter II: System Requirements

The purpose of this chapter is to describe the support resources and infrastructure necessary to operate the test station and the fuel cell. The test station requires A) oil-free compressed air, B) hydrogen supply and venting C) deionized water, D) water drainage, and E) power. Fuel cell requirements are given in terms of pressure, flow, temperature, and hydrogen-oxygen stoichiometry as discussed below.

! *Important:* If test station users make any changes to the configuration of the test station or its constituent systems, they need to understand the importance of maintaining air and water quality and the integrity of all plumbing, especially the hydrogen supply and ventilation system.

A. Test Station Requirements

1. Oil-Free Compressed Air

The test station user must provide a compressed air system, including an oil-free compressor and an air dryer. The air system will deliver dry, oil-free compressed air to the test bench. The supply line is connected to the test station air system at a black-handled manual valve located at the back top-right of the test station.

2. Hydrogen Supply and Venting

Hydrogen is supplied to the test station from Compressed Gas Association-approved Size 44 cylinders. These cylinders are held within the 2-cylinder rack to the right of the test station. Only one cylinder of hydrogen is in service at any given time. A cylinder exchange procedure is provided in Chapter III.

Two vent lines are used to vent gas from the hydrogen system. One vent line is used for manual venting and pressure relief of the section of piping between the cylinder regulator and the low-pressure regulator. This section has a nominal pressure of 100 psig with the relief point set at 150 psig and vents outside the building. The second line is a low pressure vent line for the low-pressure regulator relief valve (set at 9 psig) and purge gas exiting the hydrogen purge drum. This line vents into the hood above the test station.

3. Water Supply

The test station user must provide a filtration system that delivers DI water to the test bench. The water must be particle-free and have a conductivity of 5 μS or better. The supply line is connected to a blue-handled manual valve at the back top-center of the test station. Water drains from the system via a valve located under the water reservoir and is directed into the fuel trench in the floor.

4. Water Drainage

Three water drain hoses leave the backside of the test station and are directed into the fuel trench. These hoses include the fuel cell air exhaust line, the purge drum manual drain line, and a combined water reservoir manual drain and overflow drain line.

5. Power Supply

Power is provided to the test bench from a 30A, 120 VAC circuit hardwired into the junction box adjacent to the electrical panel on the wall behind the test station.

B. Fuel Cell Requirements

To safely operate the fuel cell stack provided, adhere to the following recommendations.

! **IMPORTANT:** Operate the stack at steady-state temperature at least once a month. This will maintain hydration of the stack's membrane electrode assemblies (MEAs), which may significantly extend stack lifetime.

1. Air Supply

- Air inlet pressure is dependent on the airflow. When at high flow rates, monitor inlet pressure closely to ensure pressure does not exceed the relief valve setpoint (150 in. WC).
- The air temperature upstream of the fuel cell should be kept above 0°C at all times.
- During continuous operation the airflow should be maintained at 200% to 300% stoichiometry (2 to 3 * 0.01659 slm/(Amp-cell)).
- The airflow rate must always exceed 0.5 slm/cell when fuel cell current exceeds 0 Amps.

2. Hydrogen Supply

- Hydrogen supplied to the test station must be industrial grade (min. 99.95% pure).
- Hydrogen must be free of carbon monoxide, hydrogen sulfide, and other catalyst poisons.
- The hydrogen delivery pressure must not exceed 6 psig.
- Hydrogen purges of approximately 1 second duration must be provided at 1 to 20 minute intervals, depending on current density.

3. Water Circulation/Temperature Control

- The water flow rate must be between 0.2 and 5.0 lpm, depending on current density and water pressure.
- Water temperature should be controlled to 50 to 65°C.
- The water temperature at the fuel cell inlet must be higher than 5°C.
- Fuel cell stack temperature must not exceed 70°C.

- Water pressure at fuel cell inlet must not exceed 100 in. WC. The pressure relief valve located near the fuel cell inlet is set to relieve pressure at 120 in. WC.

Chapter III: Test Station Hardware Operation

This chapter provides the procedures needed to prepare the test station for operation. Step-by-step instructions are provided for connecting and removing a fuel cell stack, adjusting the low pressure hydrogen regulator, initial setup of and exchange of the hydrogen gas cylinder, switching air system mass flow controllers, changing the air supply from compressed air to blower operation, powering the test station, and using the data acquisition hardware.

A. Fuel Cell Stack Connection

Tygon tubes running from the stainless steel tubing on the air, hydrogen, and water subsystems are used to supply all liquids and gases to the stack. Figure III-1 shows the locations of each of the tubes connected to the appropriate fittings on the right and left endplates of the stack as seen from the front of the stack. Figure III-2 shows the connections as seen looking directly at the left and right endplates from the side.

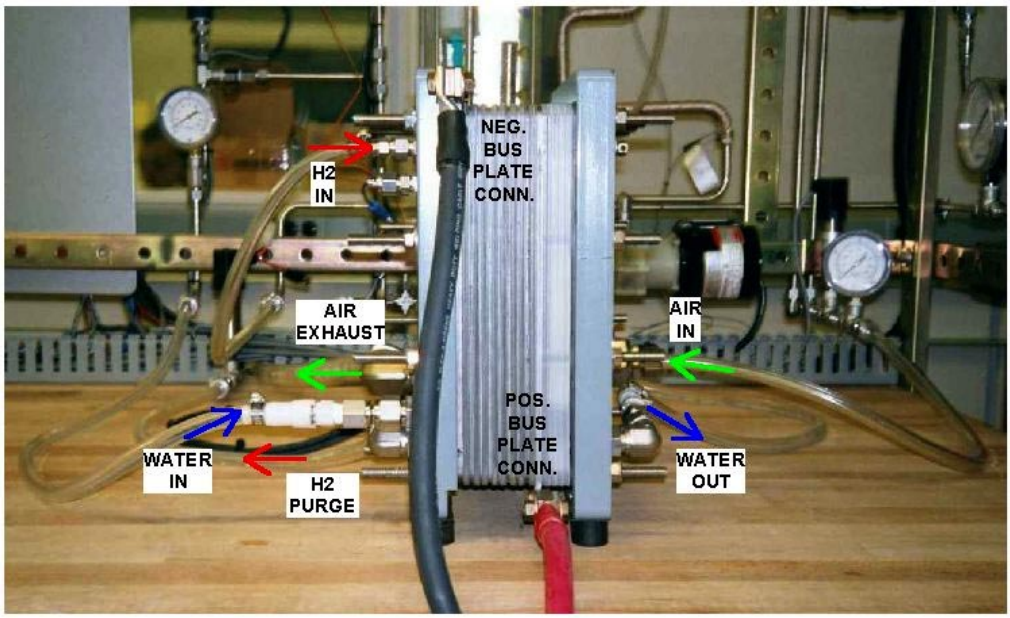


Figure III-1. Location of System Connections

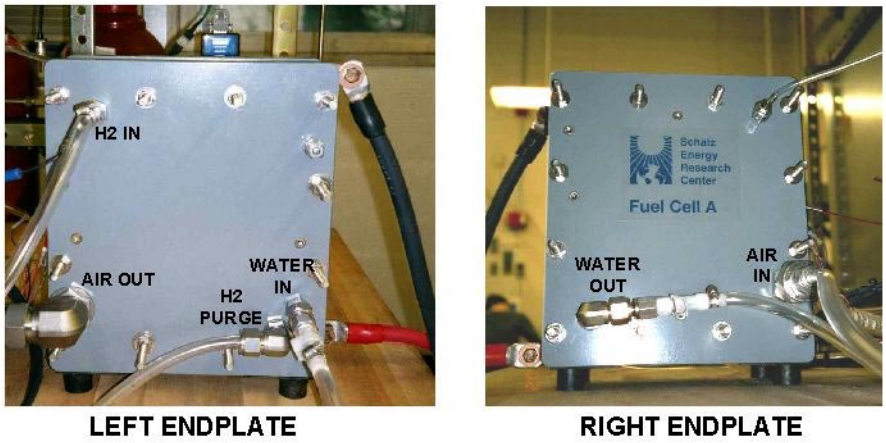


Figure III-2. Air, Hydrogen and Water Supply and Exhaust Lines

Dry compressed air enters through a 1/2" Tygon hose into the bottom right hand corner of the right endplate. Air then passes through the humidification section, into the power section, and exits through a 1" Tygon hose in the bottom left corner of the left endplate.

Hydrogen enters the top left corner of the left endplate through a 3/8" fitting and leaves, when purged, out of a 1/2" fitting on the bottom right corner of the left endplate.

! **WARNING:** The Swagelok fittings connected to the stack should be securely tightened with a wrench. Use the minimal amount of force necessary to prevent leaks. Keep in mind that all connections are for low pressure systems.

DI water enters the stack in the bottom right corner (above the purge fitting) of the left endplate, removes or supplies heat in the power section, flows through the humidification section, and leaves the stack in the bottom left corner of the right endplate. The water lines are connected to the fuel cell using plastic quick-connect fittings. A small air vent hose is connected from the bleed valve on the right end plate to the tee located on the top of the water reservoir.

Electrical connections are made to the front of the stack (the side without the VTaps). The positive (red) cable is connected tightly to the right bus plate and the negative (black) cable is tightly connected to the left bus plate.

Two cables with individually numbered alligator clips are used to monitor cell voltages. The VTaps are connected along the back of the fuel cell starting with tap 0 placed on the leftmost graphite tab when facing the front of the stack. The cell numbers increase from the left to the right with cell 1 being the first cell on the left. The VTaps are programmed in software to monitor individual cells or blocks of cells. For individual cells, place one VTap in consecutive order on every graphite tab. For cell blocks, place each VTap on the corresponding graphite tab for that cell block. For example, for monitoring blocks of 2 cells, VTaps will be placed on every other graphite tab. Figure III-3 shows the Vtaps connected to the rear of an eight-cell fuel cell stack.

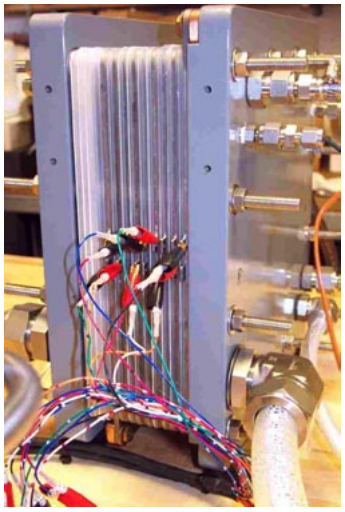


Figure III-3. Rear View of Stack Showing VTaps

To monitor temperatures inside the stack, thermocouples are placed into the desired stack manifolds and connected to the DAQ system via the electrical panel. The fuel cell operating temperature, TFC, is monitored in the water manifold as water leaves the power section (the hottest accessible place in the stack). The TFC thermocouple is placed in the fitting located in the top left corner of the left endplate below the hydrogen inlet fitting. Additional fittings must be purchased to monitor temperatures at other points in the stack.

! **WARNING:** When placing a thermocouple into the power section of the stack, the thermocouple must be electrically insulated. Should a bare thermocouple come in contact with two or more of the graphite plates, an electrical short will occur.

B. Low Pressure Regulator Adjustment

The hydrogen low pressure regulator can be adjusted to deliver gas at pressures ranging from 0.5 to 5.0 psig. The hydrogen fuel cell pressure is nominally 3.0 psig. The regulator can be adjusted during fuel cell operation (preferred) or while shut down. If adjusted during operation, make small changes and allow time for the regulator to respond and prevent a pressure surge. When the regulator is adjusted while shut down, the hydrogen supply solenoid valve must be open to provide pressure indication (pressure gauge and pressure transducer) and gas must flow through the regulator. A pressure relief valve is built into the regulator and has a non-adjustable relief setpoint at 9 psig.

! **WARNING:** Note that the built-in relief valve relieves gas into the housing where the adjustment screw is located. If the relief valve lifts with the access plug out or loose, hydrogen will vent into the atmosphere through the open port and not through its designated vent line. Be sure the access plug is tight when pressure adjustment is complete.

The low-pressure hydrogen regulator adjustment procedure is as follows:

1. Remove the black plastic access plug by turning counter-clockwise.

2. Using a flat-bladed screwdriver, turn the adjustment screw to change the delivery setpoint. Turn the nut clockwise to increase the pressure and turn counter-clockwise to decrease the pressure.
3. Once the desired pressure is reached, replace the access plug and tighten snugly.

C. Hydrogen Cylinder Initial Set-up and Exchange

The following provides step by step instructions for initial cylinder set-up and for cylinder exchange. The hydrogen cylinder should be exchanged when the cylinder pressure gauge indicates 100 psig. Pressure must be left in the cylinder after use to prevent air from entering and contaminating the cylinder. For cylinder exchange, perform all steps outlined below. For initial cylinder set-up, begin with step 9.

1. Ensure the test station is shut down.
2. Close the cylinder valve.
3. Close the hydrogen supply manual valve located upstream of the filter and the low pressure regulator.
4. Open the delivery valve.
5. Slowly open the hydrogen vent valve to depressurize the piping from the cylinder valve to the hydrogen supply valve. Pressure indication on both the regulator supply and delivery gauges should drop to 0 psig. If pressure does not decrease, ensure the blue-handled regulator valve is open and the regulator adjustment knob is turned clockwise a few turns.
6. When pressures indicate 0 psig, close the regulator outlet valve and turn the regulator adjustment knob completely counterclockwise.
7. Disconnect the regulator by loosening the CGA nut by turning clockwise. Note that hydrogen CGA fittings are reverse-threaded (clockwise to loosen, counter-clockwise to tighten).
8. Hang the regulator from the support provided ensuring that there is no stress on the flex hose.
9. Reinstall the safety cap on the cylinder. Unfasten the cylinder safety chains and move the spent cylinder from the bracket and secure to the off-service position or remove from the area using a cylinder dolly.
10. Secure the full replacement cylinder in place. Remove the full cylinder's safety cap and inspect and clean the threads on the cylinder's outlet fitting.
11. Install the regulator by securely tightening the CGA nut onto the cylinder (counter-clockwise). If necessary, tighten the flex hose from the regulator to the hydrogen plumbing inlet tee.
12. Close the hydrogen vent valve and make sure the hydrogen supply manual valve located upstream of the filter and the low pressure regulator is closed.

13. Crack open then immediately close the cylinder valve. Perform a leak check of the cylinder CGA fitting by monitoring gauge pressure or using a soap solution. If a leak is found, tighten the fitting and recheck until a leak no longer exists.
14. Open the cylinder valve 2 turns.
15. Turn the adjustment knob clockwise until 80 psig is indicated on the delivery gauge.
16. Open the regulator outlet valve. Perform a leak check of the flex hose fittings using a soap solution. If a leak is found, tighten the fitting and recheck until a leak no longer exists.
17. Crack open then close the vent valve to purge any entrained air from the system.
18. Open the hydrogen supply manual valve. The hydrogen system is ready for service.

D. Switching Air Mass Flow Controllers

The air system is equipped with both a low range (0-20 slm) and a high range (0-200 slm) mass flow controller. To switch from one controller to the other, the test station must be shut down.

1. Close the AIR SUPPLY SOLENOID on the front panel.
2. Switch the cable to the desired controller. Loosen the two screws on the cable connector, pull the connector off, attach the connector to the other controller and tighten the screws.
3. Point the 3-way inlet valve to the desired controller. The valve handle points toward the in-service controller.
4. Disconnect the air inlet line from the stack.
5. See Section IV.C.2 for software procedures

E. Air Blower Operation

An air blower can be used as an alternative source of air for the fuel cell stack. Because of the pressure drop across system components and plumbing, an air blower does not have the capability to supply the necessary amount of air through the system plumbing used for pressurized air. The blower should instead be plumbed directly to the fuel cell using large diameter hose to minimize head loss.

The type of blower installed will dictate how the blower is integrated with the existing hardware. A 24 VDC bus is available (next to the digital backplane) for powering the blower. If the 24 VDC bus is used, a digital output should be used to switch the blower on and off in software. A 120 VAC switched outlet is also provided, on the electrical panel, for controlling such devices. Regardless of the blower power supply voltage, signal voltages can be provided to the blower controller using one of the analog output channels.

Use the following procedure to switch to air blower operation:

1. Shut down the test station.

2. Replumb the air delivery system to accommodate the blower. Do not attempt to use the air delivery hardware that is connected to the MFCs. For the current blower control algorithm to work, an airflow transducer must be installed.
3. Power the blower. If using AC, plug the blower into one of the switched outlets and note which outlet you used. If using DC, plug the DC power supply into an AC switched outlet.
4. Connect the analog input wires from the airflow meter to the BLOWER AIRFLOW channel on the analog input backplane.
5. Connect the analog input wires for the pressure transducer into the BLOWER PRESSURE channel.
6. Connect the power lines for the transducers.
7. Connect the analog output wires to the blower motor controller *(the analog output signals can not be used to source more than 20mA).*

See section IV.C.1 for the software modifications necessary to operate a blower.

F. Test Station Power

The Safety Tray contains the high level safety relays, the electrical system components (fuel cell contactor and current shunt), and additional electrical hardware. Figure III-4 contains a picture of the control panel on the safety tray.

Figure III-4. Front Panel of the Safety Tray

The 15A, 120 VAC circuit supplied from the UPS to the Safety Tray (circuit #1) can be manually disconnected using the ON/OFF switch located on the right hand side of the front panel. The Emergency Stop button is in series with the manual disconnect and when pressed will also disconnect the 15A circuit to the safety tray.

Five LED safety and power indicators are used to display the status of the safety and power circuits. The H_2 SENSOR, SMOKE, and VENT indicators display whether one of the high level faults has triggered. When no safety faults have occurred, all three indicators will be green. If the H_2 SENSOR trips, all three indicators will be red. If the SMOKE ALARM trips, the SMOKE and VENT indicators will be red. If the VENT alarm trips, only the VENT indicator will be red. If any of these high level faults are triggered, the 15A, 120VAC circuit supplying power to the Safety Tray will be disconnected.

However, these individual faults do not latch. Consequently, a latching safety relay and a SAFETY STATUS LED are used to latch the status of the safeties. If any high level safety fault occurs, the SAFETY STATUS LED will remain red and the 15A circuit will remain disconnected until the Safety Enable button is pressed.

The final LED indicator is the BACKPLANE POWER LED. It is green when 5VDC power is being supplied to the backplanes.

Three control buttons are located on the left side of the front panel. The red BACKPLANE START button is used to bypass the watchdog timer and supply 5VDC to the backplanes at startup. (Review the Safety Control System section of Chapter I for a review of the safety system.) The SAFETY ENABLE button is used to unlatch a safety fault. When a high level fault occurs, an alarm sounds and continues to sound until the SAFETY ENABLE button is pressed. Alternatively, the SIREN BYPASS button can be pressed to silence the siren after a fault.

For a detailed description of the operation of the Safety Tray during system startup, refer to the Software Startup and Shutdown section of Chapter IV.

Power supplied to the electronic load and to the control computer and computer monitor are supplied via circuit #2 on the UPS (15A, 120VAC). This power is not switched off under any safety condition. Power will continue to be supplied to these components from the UPS even if the AC input power to the UPS is disconnected (e.g. at the main electric service panel).

Chapter IV: Test Station Software

The purpose of this chapter is to instruct test station users in the operation of the front panel, a computer interface used to control and monitor the test station and the fuel cell stack. This chapter also covers how to make permitted modifications to the test station software and how to perform special testing procedures.

A. Software Description

LabVIEW™, produced by National Instruments Corporation, is a programming language used in industrial and laboratory automation. To operate, maintain and modify the test station software, it is necessary to have some understanding of the LabVIEW™ programming environment. It is strongly recommended that any test station operator read the LabVIEW™ user manual and complete the online tutorials included with the LabVIEW™ software before modifying the test station software in any way.

LabVIEW™ programmers interact with two different interfaces, namely the front panel and the block diagram. The front panel is the operator interface used to control and monitor the test station. A hardware state, configurable parameter, or safety condition can be manipulated using the controls on the front panel, and physical phenomena are measured and displayed using indicators and graphs on the front panel. The controls and indicators are organized by test station system and arranged by color.

The block diagram is a physical representation of the control software. It is the interface used to write and modify the control logic. The only time test station users should access and make changes to the block diagram is if they want to modify the test station control software.

1. Front Panel

The front panel is divided into eight areas: air, hydrogen, and cooling system control boxes; stack monitoring display; safeties control box; dynamic graphing tab control; settings tab control (configurable parameters); and error status. Figure IV-1 includes a screen shot of the test station software front panel along with the location of the controls and indicators for each subsection. The controls and indicators within each area are described below. Each test station system and its respective settings are presented together.

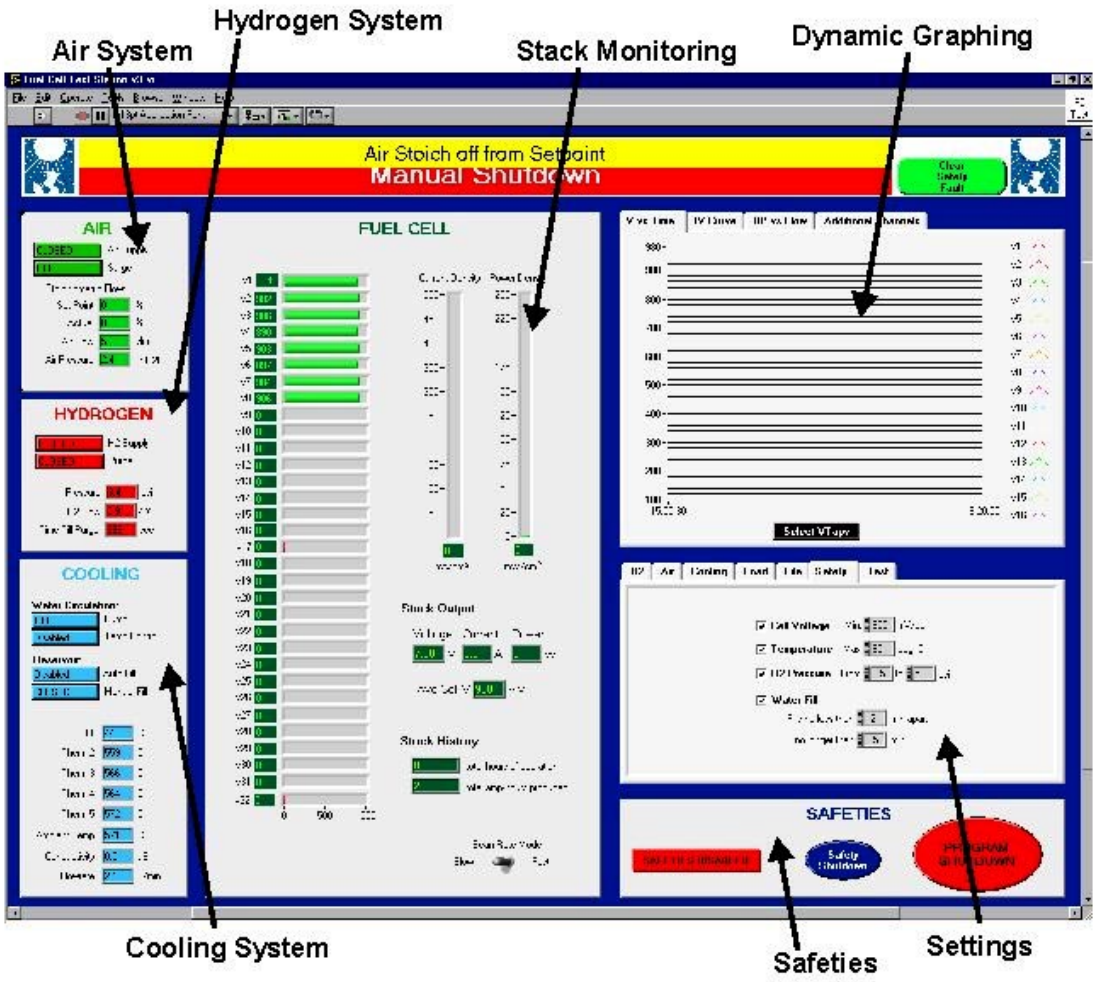


Figure IV-1. Software Front Panel

Air Subsystem and Settings

Table IV-1 lists the controls, indicators, and settings for the air subsystem.

Table IV-1. Air Subsystem Controls, Indicators, and Settings

Controls	Indicators	Settings
• Air Supply • Air Surge	• Setpoint Air Stoichiometry (%) • Actual Air Stoichiometry (%) • Airflow (slm) • Air Inlet Pressure (in. H_2O)	• Air Source (Blower or MFC) • MFC Calibration • Blower (Airflow Sensor) Calibration • Airflow Mode (Fixed or Stoichiometric) • Fixed Flow (slm) • Minimum Stoich. Flow (%) • Setpoint Stoichiometry (%) • Surge Factor (x flow)

Figure IV-2 contains a diagram of the AIR controls, indicators and settings. There are two possible sources of air for the test station: a blower or a mass flow controller (MFC). An MFC requires a supply of compressed air for controlling airflow. The desired AIR SOURCE is selected using the left set of tabs in the AIR settings tab control. Calibrations necessary for using either a blower or an MFC are included in the selected AIR SOURCE frame. The AIR SOURCE and associated calibrations should not be changed while the program is running.

! **WARNING:** Changing the MFC or BLOWER calibrations while the program is running may damage the fuel cell. The program responds instantaneously to changes in the calibration curve formula. Since only one variable in the formula can be entered at a time, the airflow might be much greater than intended for brief periods during formula entry.

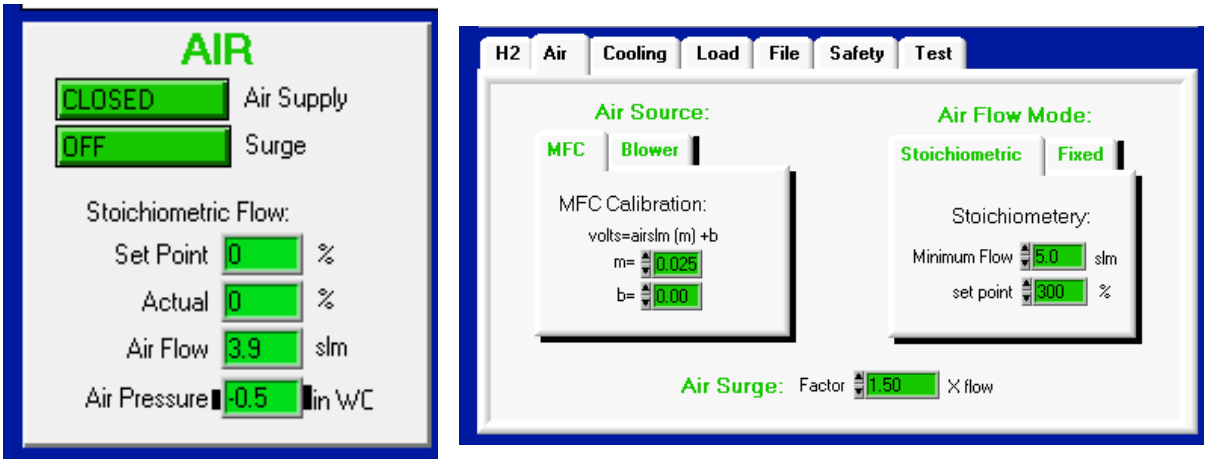


Figure IV-2. Front Panel Air Controls, Indicators and Settings

In addition to the two possible sources of air, there are two different airflow modes: stoichiometric and fixed. The AIRFLOW MODE is selected using the right hand set of tabs

in the AIR settings tab control. If FIXED flow is chosen, the operator can set a constant airflow rate. If STOICHIOMETRIC flow is selected, the operator can set a minimum flow rate and a setpoint, or target, stoichiometry. The stoichiometric flow delivered to the stack is dependent upon the setpoint stoichiometry, the number of cells in the stack, and the amount of current drawn from the stack as described by:

$$\text{flow (slm)} = 0.0166 \frac{slm\ Air}{cell - Amp} \bullet \left(\frac{S}{100}\right) \bullet I \bullet N$$

Where: S = Air stoichiometry (%)
I = Stack current (Amps)
N = Number of cells in stack

In the STOICHIOMETRIC airflow mode, the greater of either the minimum flow or the stoichiometric flow is delivered to the stack.

In the AIR system control box, the AIR SUPPLY control operates the air supply solenoid valve or a digital control on the blower power supply. It is used regardless of the AIR SOURCE selected. When the MFC is selected as the AIR SOURCE and the AIR SUPPLY is closed, the solenoid valve is de-energized (closed) and a 0 volt control signal is sent to the air MFC via an analog output module. When the AIR SUPPLY is open, the air solenoid is energized (open) and airflow is dependent upon the airflow settings.

When the BLOWER is selected as the AIR SOURCE, and the AIR SUPPLY is closed, a digital signal is provided to a relay controlling the power supply to the blower. When the relay is opened a 0 volt control signal is sent to the blower motor controller via an analog output module. When the AIR SUPPLY is open, the relay is closed and the desired airflow control signal is sent to the blower. While the air SURGE button is depressed, the desired airflow will be multiplied by the surge FACTOR specified in the bottom of the AIR settingS tab control.

In the AIR system control box, the indicators displayed below the air controls depend upon the air settings. If the airflow mode is FIXED, the stoichiometry SETPOINT is not displayed. If the airflow mode is STOICHIOMETRIC, the SETPOINT is displayed. Regardless of the AIRFLOW MODE, the ACTUAL stoichiometry, AIRFLOW, and inlet AIR PRESSURE are displayed.

Hydrogen Subsystem and Settings

Table IV-2 lists the controls, indicators, and settings for the hydrogen subsystem.

Table IV-2. Hydrogen Subsystem Controls, Indicators, and Settings

Controls	Indicators	Settings
• H_2 Supply	• H_2 Inlet Pressure (psig)	• Purge Enabled
• H_2 Purge	• H_2 Flow (slm)	• Purge Duration (sec)
	• Time Till Purge (sec)	• Purge Period (min)

Figure IV-3 contains a diagram of the HYDROGEN controls, indicators and settings.

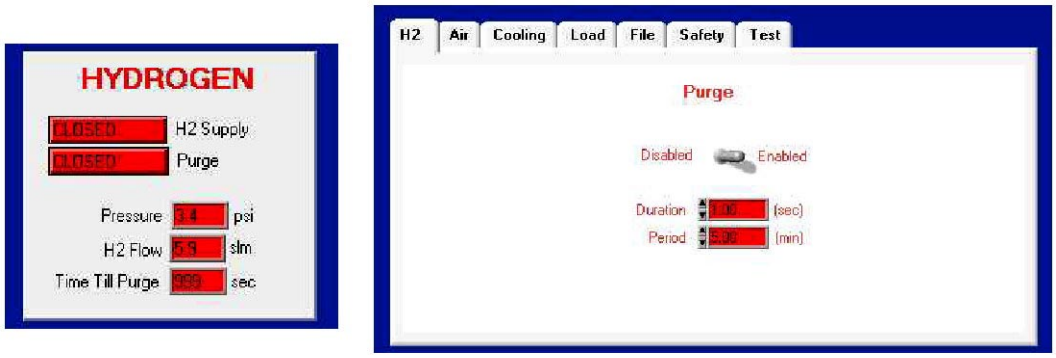


Figure IV-3. Front Panel Hydrogen Controls, Indicators and Settings

The H2 SUPPLY button in the HYDROGEN system control box is used to control the supply solenoid valve that is located upstream of the stack. The Hydrogen PURGE button controls the purge solenoid valve, which is located downstream of the stack. When the fuel cell is running under normal operation, the supply solenoid is open and the purge solenoid is closed (except for purging as described below).

Because the hydrogen pressure delivered to the stack is regulated, opening the purge solenoid valve greatly increases the hydrogen flow through the stack (the regulator is trying to maintain the desired delivery pressure while the pressure exiting the hydrogen system is at atmospheric pressure). This rapid increase in hydrogen flow, while both the supply and purge solenoid valves are open, is referred to as purging. Automated purging of the stack is controlled in the H2 settings tab control. Automatic purging can be enabled or disabled using the DISABLED/ENABLED toggle switch. Purges last for the time designated by DURATION and the time interval between purges is specified by PERIOD. Automatic purging can be overridden using the PURGE control in the HYDROGEN system control box. When the purge button is pressed the purge solenoid is opened and remains open until the PURGE button is released. Manual purges will not affect the automatic purge sequence (will not reset the purge timer or affect the purge period or duration).

The hydrogen inlet PRESSURE, H2 FLOW, and TIME TIL PURGE indicators are displayed below the hydrogen controls in the HYDROGEN system control box. When the automatic purging is not enabled, the TIME TIL PURGE indicator will display 999 seconds.

Cooling Subsystem and Settings

Table IV-3 lists the controls, indicators, and settings for the cooling subsystem.

Table IV-3. Cooling Subsystem Controls, Indicators, and Settings

Controls	Indicators	Settings
• Pump • Temp Control • • Auto Fill • Manual Fill	• TFC (°C) • Ambient Temp (°C) • Therm 2 (°C) • Therm 3 (°C) • Therm 4 (°C) • Therm 5 (°C) • Conductivity (µS) • Flow rate (L/min)	• Set Point Temperature (deg. C) • High Dead Band (deg. C) • Low Dead Band (deg. C) • Pulse Period (sec) • Reservoir Fill Time(sec.)

Figure IV-4 contains a diagram of the COOLING controls, indicators and settings.

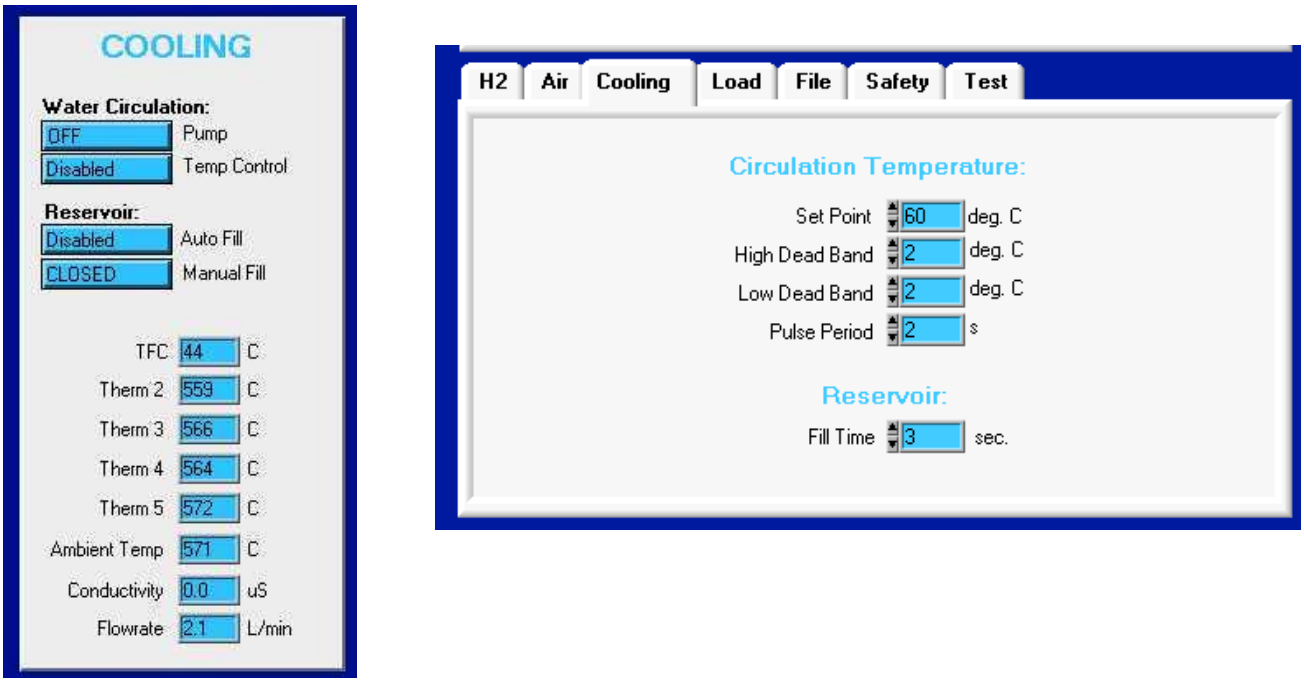


Figure IV-4. Front Panel Cooling Controls, Indicators and Settings

The water circulation pump circulates water from the water reservoir, through the heat exchanger, to the fuel cell and back to the reservoir. The water is heated or cooled to maintain a desired water temperature, as measured by the fuel cell thermocouple (TFC) or any thermocouple connected to THERM 1, within the SET POINT temperature range. TFC is located in the water manifold as water is leaving the power section and entering the humidification section.

Water heating is accomplished using cartridge heaters in the reservoir and heat tape on the tubing leaving the pump. Cooling is achieved using fans mounted to the heat

exchanger. The SET POINT temperature will be maintained using the HIGH and LOW DEAD BANDS selected in the COOLING settings tab control.

To allow for automated control over the heating and cooling of the stack, two separate temperature ranges and algorithms are used. When heating, the heaters are controlled using pulse width modulation. The heating temperature setpoint is calculated as the SET POINT minus the LOW DEAD BAND minus 2°C and will be referred to as the calculated heating setpoint temperature. When the temperature is below the calculated setpoint minus the LOW DEAD BAND the heaters are on; when it is above the calculated setpoint plus the HIGH DEAD BAND the heaters are off. When the temperature is between the LOW and HIGH DEAD BAND temperatures the heaters are pulsed. Pulsing of the heaters depends on the calculated setpoint, the two DEAD BANDS, and the PULSE PERIOD.

When cooling the stack, the fans are on when the temperature exceeds the value of the SET POINT plus the HIGH DEAD BAND, and the fans are off when the temperature is below the value of the SET POINT minus the LOW DEAD BAND.

The pump can be directly controlled using the PUMP control in the COOLING system control box. However, the TEMP CONTROL button does not provide direct control over the heaters or fans. When the TEMP CONTROL button is enabled the temperature of the water circulation system at the point where TFC is measured determines whether the heaters or fans are on.

A float switch is used to control filling of the water reservoir and maintain an adequate water level in the reservoir. When the AUTO FILL control is enabled and the water level drops the float to its lowest setting, the float switch closes and the water fill solenoid valve opens. The water fill solenoid valve will remain open until the float switch opens and then remain open for a preset period of time as specified by the reservoir FILL TIME in the COOLING SETTINGS tab control. Pressing the MANUAL FILL button will directly open the water fill solenoid valve and fill the reservoir for as long as the button is depressed.

The indicators displayed below the cooling controls in the COOLING system control box include the fuel cell operating temperature (TFC, located on THERM 1), AMBIENT TEMP, additional thermocouples (THERM 2 through THERM 5), water FLOWRATE, and water CONDUCTIVITY. Temperature probe locations and labels can be easily changed as described in the Modifying Software section of this chapter.

Fuel Cell Subsystem

Table IV-4 lists the indicators used to monitor the fuel cell.

Table IV-4. Fuel Cell Indicators

Indicators
• Vtaps (1-32) (mV)
• Stack Voltage (V)
• Stack Current (A)
• Stack Power (W)
• Current Density (mA/cm^2)
• Power Density (mW/cell/cm^2)
• Total hours of operation
• Total amp-hours-produced

Figure IV-5 contains a diagram of the fuel cell indicators.

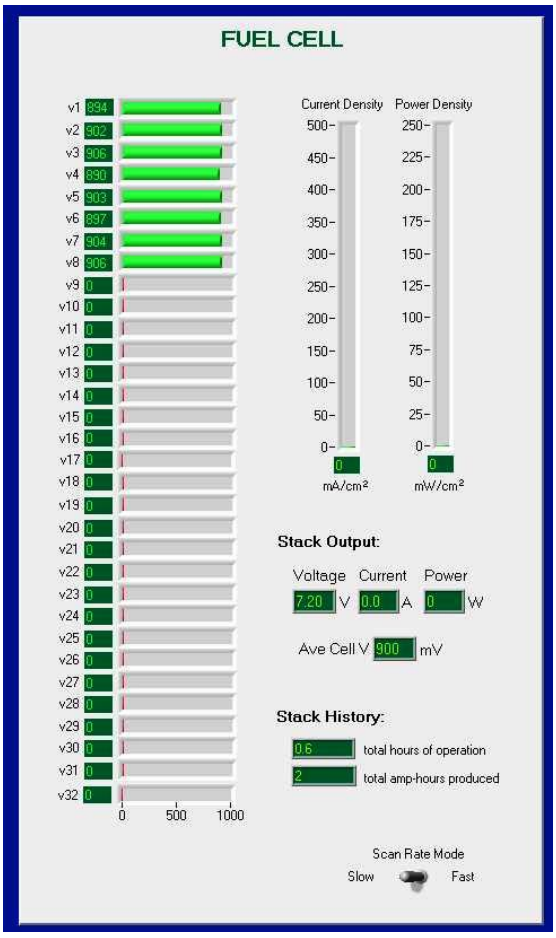


Figure IV-5. Front Panel Fuel Cell Indicators

Individual cells or cell blocks are monitored with up to 32 voltage taps (Vtaps). If, for example, a 60-cell stack were monitored, 30 voltage taps could be placed on every other

cell such that each tap monitored the total voltage across a pair of adjacent cells. The VTap displays on the front panel would indicate the average cell voltages for each 2-cell block being monitored. The total stack VOLTAGE, CURRENT, and POWER are also displayed along with the stack CURRENT DENSITY and POWER DENSITY. Under STACK HISTORY, the fuel cell hour counter (TOTAL HOURS OF OPERATION) displays the number of hours the stack has run at a current greater than 0.3 Amps. The fuel cell amp-hour counter (TOTAL AMP-HOURS PRODUCED) displays the cumulative number of amp-hours the stack has produced, also at a current greater than 0.3 Amps. These counters can be reset when a new fuel cell stack is installed on the test station.

Located at the bottom of the FUEL CELL indicators box is a toggle control used to manipulate the data acquisition scan rate. The graphics used to display data to the test station operator are CPU intensive and decrease the rate at which data can be collected. Consequently, when high-speed acquisition is necessary, the SCAN RATE MODE control can be set to the FAST position and the dynamic graphing and settings tab controls will not be displayed.

Safety Controls and Settings

Table IV-5 lists the controls and settings for the test station safeties.

Table IV-5. Safety Controls and Settings

Controls	Settings
• Program Shutdown • Safety Shutdown • Safeties Enable	• Cell Voltage Enable • Minimum Cell Voltage (mV/cell) • Temperature Enable • Maximum Temperature (deg. C) • H2 Pressure Enable • Minimum H2 Pressure (psig) • Maximum H2 Pressure (psig) • Water Fill Enable • Fill no less than __ min apart • Fill no longer than __ min

Figure IV-6 contains a diagram of the safety controls and settings.

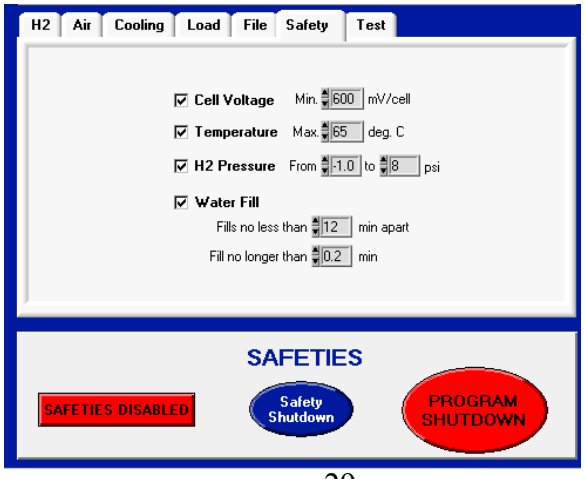


Figure IV-6. Front Panel Safety Controls and Settings

The SAFETY settings, which are accessible in the SAFETY settings tab control on the front panel, are for low-level/software faults. In the SAFETY settings both checkboxes and thresholds are used to set fault parameters. If a check box is enabled (checked), then the variable of interest will be compared to the threshold setpoint. If the variable falls outside of the threshold range, a low-level/software shutdown will occur. When a low-level fault occurs, the test station is placed in a safe state (solenoid valves closed, contactors opened, signal outputs set to 0V, etc.)

The CELL VOLTAGE enable prevents the fuel cell from running under load if a cell voltage is less than the minimum CELL VOLTAGE. The TEMPERATURE enable ensures that the fuel cell operating temperature remains below the maximum TEMPERATURE. The H2 PRESSURE enable ensures a hydrogen pressure between the minimum and maximum specified values. The WATER FILL enable is used to ensure that the reservoir is not filled for too long or too often. In addition, to enable any of the low-level safeties the SAFETY ENABLE control (located in the SAFETIES control box) must be enabled.

In summary, to generate a low-level fault: the safeties must be enabled, the appropriate safety setting enable checkbox must be checked, and one of the conditions monitored must fall outside of the specified range. For example, assume the minimum cell voltage is set at 500 mV. If VTap 4 falls to 480 mV, a low-level fault will be triggered if the CELL VOLTAGE enable box in the SAFETY settings is checked and the SAFETIES are enabled.

! **WARNING**: During normal operation, all of the low-level faults should be enabled. Following system startup, the test station should be operated with the safeties enabled as soon as the cell voltages are above the minimum threshold.

The SAFETY SHUTDOWN control, when depressed, simulates a low-level fault condition. During a low-level safety shutdown, the hardware is placed in a safe state, the data file remains open for the time period set in the FILE settings tab control, and the test station program continues to run. In contrast, when the PROGRAM SHUTDOWN control is pressed, all hardware is placed in a safe state, the current data file is closed, and the test station program is stopped.

Load Settings

Table IV-6 lists the settings for the electronic load.

Table IV-6. Load Settings

Settings
• Enable Load
• Range
• Mode
• Constant Current Controls
• Pulsing Controls
• IV Curve Controls

- Driving Cycle Controls

Figure IV-7 contains a diagram of the LOAD SETTINGS tab control when running in constant current mode. Whenever changes are made to the load settings, the DynaLoad driver updates the electronic load using GPIB communication. The load is updated only after a change to the settings has been made.

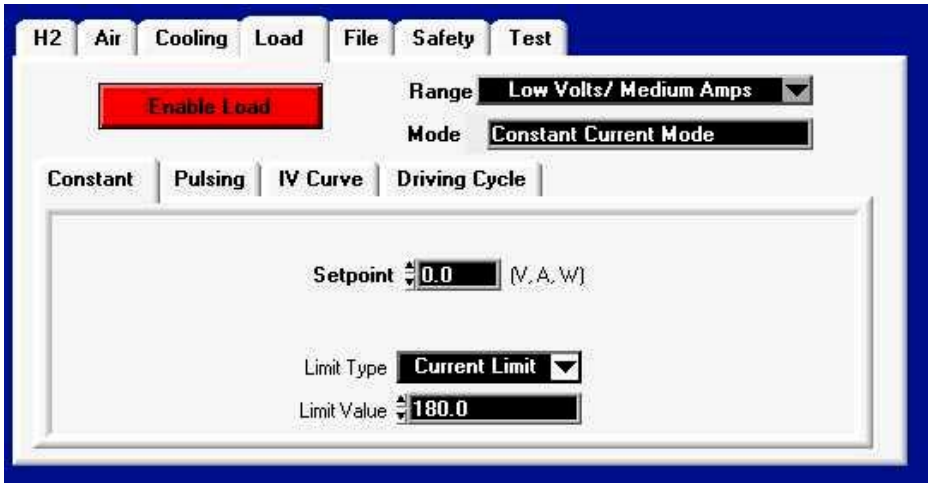


Figure IV-7. Front Panel Load Settings

The ENABLE LOAD button is used to control the fuel cell contactor (located in the safety tray) and also the contactor contained within the load itself. When the load is enabled both contactors are closed, and when the load is disabled both contactors are open. The load has three ranges (low, medium, and high) for the current and the voltage. These are selectable using the RANGE control. Refer to the Electronic Load Operation/Programming Manual in Appendix B for details regarding these ranges. There are also four main MODES that the load can operate in: CONSTANT CURRENT, CONSTANT VOLTAGE, CONSTANT POWER, and CONSTANT RESISTANCE. The mode that the load runs in is set using the MODE control.

The second level tab control in the LOAD settings is used to set the limits and conditions under which the load operates. Figure IV-7, above, displays the LOAD settings during CONSTANT operation. The SETPOINT control is used to set the fixed value (either current, voltage, or power depending upon the MODE selected) at which the load operates. For example, if the MODE is set to CONSTANT CURRENT and the SETPOINT is set to 20, the load will draw 20 Amps from the fuel cell. The LIMIT TYPE and LIMIT VALUE are used to set an upper limit on either current, voltage or power. Note: The MODE and the LIMIT TYPE do not have to be set for the same variable. For example, the MODE could be set to CONSTANT CURRENT and the LIMIT TYPE could be set to limit MAXIMUM POWER.

Figure IV-8 displays the LOAD SETTINGS tab control when the load is being pulsed. The RUN button is used to start the series of pulses. When the pulsing is finished the RUN button will return to the OFF state. If the value of any parameter changes, the software

will detect a change and will send an update of all values to the load. The FREQUENCY/DUTY CYCLE or the BASELINE (μs) and INCREMENT (μs) values set the frequency at which the pulses occur and the length of time that the pulse remains high . The BASELINE value is used to set the bottom of the pulse and the sum of the BASELINE and the INCREMENT set the value of the top of the pulse. Either the voltage, current or power can be controlled during pulsing, depending upon the MODE selected. The NUMBER OF PULSES control is used to set the number of pulses that will occur after the RUN button is set to the ON state. The SLEW RATE (μs) and SLEW MODE are additional controls used to manipulate the length of time that pulses occur and the transition times when pulsing. For a detailed description of these controls refer to the Electronic Load Operation/Programming Manual in Appendix B.

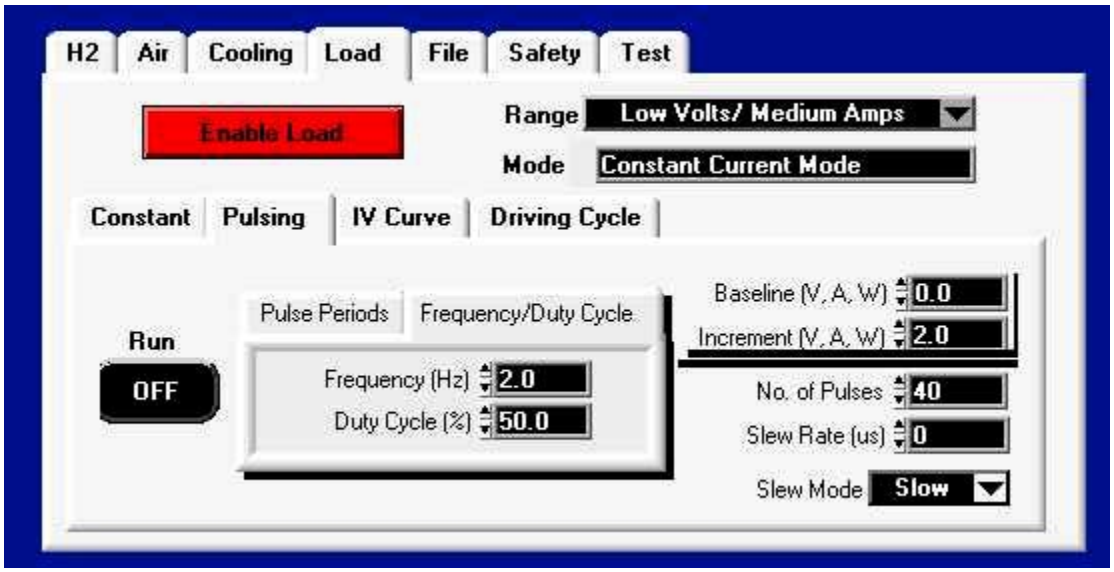


Figure IV-8. Front Panel Load Settings When Pulsing the Load

Figure IV-9 displays the setting for performing a polarization (IV) curve. During an IV curve the current is varied while the cell voltages, and other variables, are monitored. The IV curve should not be taken to a current that results in mass transport limitation or in any individual cell voltage being less than 500 mV.

! **WARNING:** The OHMIC END CURRENT should never be great enough to reduce the lowest cell voltage below 500mV or result in mass transport limitation. The SAFETIES should always be enabled while IV curves are being conducted.

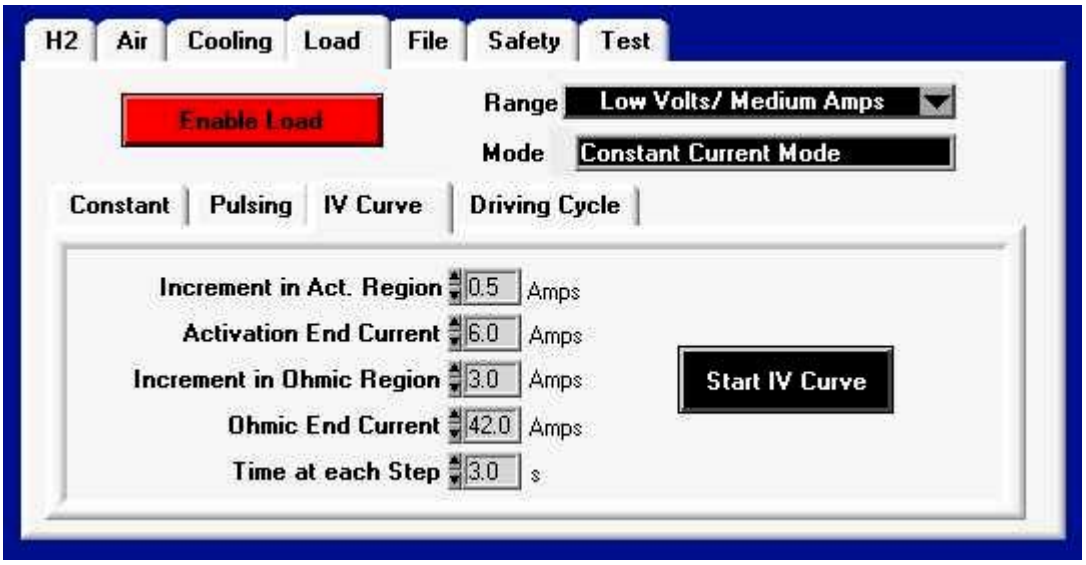


Figure IV-9. Front Panel Load Settings When Running an IV Curve

The IV CURVE settings are split into two regions: activation and ohmic resistance. The ACTIVATION END CURRENT should be set to a value just beyond the activation region. The INCREMENT IN ACT. REGION determines the current increments throughout the activation region. The OHMIC END CURRENT is the current at which the IV curve stops. The INCREMENT IN OHMIC REGION controls the current increment for the Ohmic resistance portion of the curve. The TIME AT EACH STEP control is used to determine the amount of time that each increment in current will last.

For example, if the end of the activation region occurs at approximately 6 Amps, the ACTIVATION END CURRENT should be set to 10 Amps. The INCREMENT IN ACTIVATION REGION should be set to a small value (such as 1 Amp) because small changes in current cause relatively large changes in the cell voltages in this region of the IV curve. Based on stack performance and the testing objectives, the OHMIC END CURRENT and the INCREMENT IN OHMIC REGION can be set. Typically, IV curves range from 0-600 mA/cm^2 (180 Amps for the stack provided) and current increments of 3 Amps in the Ohmic region are satisfactory. The TIME AT EACH STEP should take into consideration the response time of the instruments you are controlling. Using mass flow controlled air and regulated hydrogen, the time period should be at least 2 seconds to enable a quasi-equilibrium in the fuel cell to be reached.

Using the IV Curve settings provided the IV curve will progress as follows . When the START IV CURVE button is depressed, a separate data file will be opened. The current will increase from 0 to 10 Amps, in 1 Amp increments. After remaining at 10 Amps for the set number of seconds, the current will increase to 13 Amps and continue increasing in 3 Amp increments until 180 Amps (or greater if the increment does not equal the OHMIC END CURRENT) is reached. After the end current is reached the IV Curve will stop, the IV curve data file will close, and standard testing will resume.

File Settings

There are two interfaces for manipulating data files: the FILE SETTINGS tab control and a DATA FILE dialog box included during startup. The FILE SETTINGS are used to control how the data files are written, whereas the DATA FILE dialog is used to control the contents of the data files. For a detailed description of the DATA FILE dialog refer to the Software Startup and Shutdown section of this chapter.

Table IV-7 lists the settings for the all data files.

Table IV-7. File Settings

Settings
• Close Data File • Data File Prefix • New File at Midnight • Take Data for _ minutes after fault • Max Time between file writes

Figure IV-10 shows the FILE settings tab control. The CLOSE DATA FILE control is used to manually open and close a data file, usually between tests. The DATA FILE PREFIX control is used to set the file name prefix. After the prefix the date and time the file was opened is appended to the file name. If the operator wishes to start a new data file at midnight each night (to prevent the creation of very large data files during long term operation) the NEW FILE AT MIDNIGHT checkbox should be selected.

After a low-level fault is detected, data will be written to the data file for the length of time entered in the TAKE DATA FOR _ MINUTES AFTER FAULT control. Data are written to the data file every time one of the variables written to the file has changed by more than the selectable threshold (specified in the DATA FILE dialog) since the last time data were written to the file. If the variables are not changing by more than the threshold, data are written to the file every MAX TIME BETWEEN FILE WRITES.

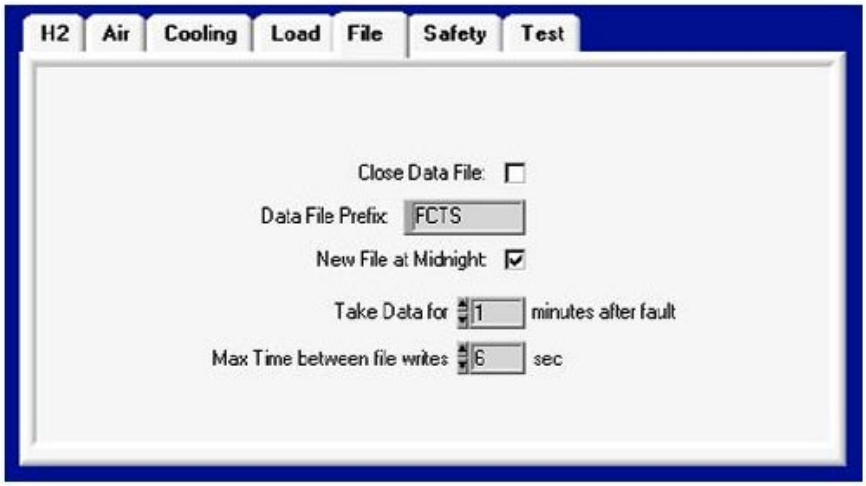


Figure IV-10. Front Panel File Settings

Test Settings

Table IV-8 and Figure IV-11 display the TEST settings.

Table IV-8. Test Settings

Settings
• Stop Program at _ FC Hours • DAQ Scan Rate (Hz)

The TEST settings tab control is used to control the parameters associated with individual tests. A test can be terminated when the fuel cell has accumulated a certain number of hours under load by using the STOP PROGRAM AT _ FC HOURS control. The DAQ SCAN RATE control can be used to specify the amount of time that elapses between consecutive scans of the backplanes. Scanning of the backplanes consists of acquiring the analog input data from all four analog input backplanes, sending the analog output data from both analog output backplanes, and sending and receiving data on the digital lines. Data acquired from the backplanes are not buffered. If the DAQ SCAN RATE is increased beyond the speed at which the program is capable of iterating, the program will iterate as fast as possible. If faster scan rates are desired, the SCAN RATE MODE control should be placed in the FAST position. This mode of operation avoids updating processor-intensive displays and results in faster program iterations.

Figure IV-11. Front Panel Test Settings

Dynamic Graphing and Spare Indicators

The dynamic graphing area is used to display data. Figure IV-12 displays the dynamic graphing tab frames and the cell voltage plots.

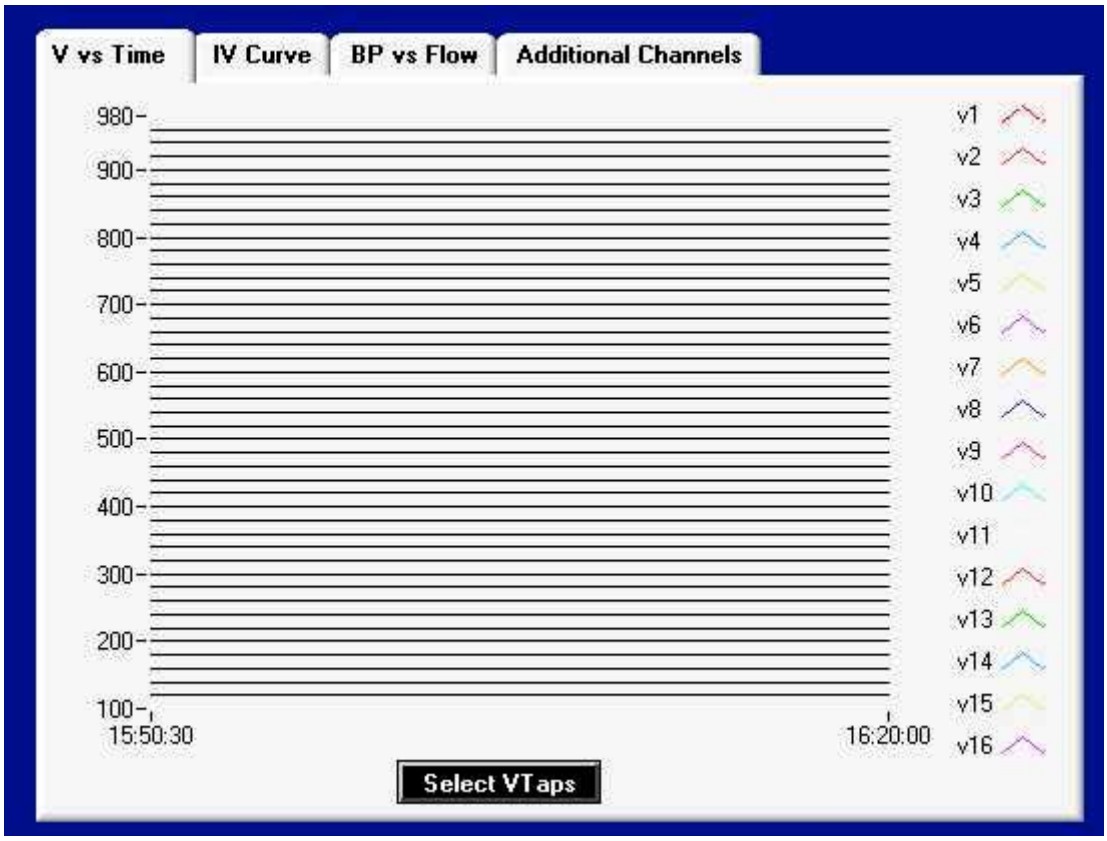


Figure IV-12. Front Panel Cell Voltage Plots

The V VS TIME, IV CURVE, and BP VS FLOW tabs display plots of cell voltages over time, average cell voltage versus current density, and air inlet pressure versus airflow, respectively. Each plot displays data even if its tab is not selected. Consequently at any time a different plot is selected, historical data can be viewed. Each plot has a limit to the number of points that can be plotted, and the period over which data are displayed depends upon the HISTORY SIZE (number of points plotted) and the display rate to the screen (controlled in the DISPLAY TASK subroutine). The ADDITIONAL CHANNELS tab is included for displaying data from instruments that are added to the test station. Refer to the Modifying Software section of this chapter for a detailed description of adding instruments.

While observing individual cell block voltages over time, the user can select which blocks to monitor. Pressing the SELECT VTAPS button will display a dialogue box that will prompt the user to choose which cells to monitor. Once the appropriate cells have been selected, the plot will be erased and new data will be displayed. The X RANGE control is used to manipulate the length of time that data will be displayed for. After changing the X RANGE and waiting for the selectable amount of time to elapse, if the data does not span the entire width of the graph, then the HISTORY SIZE is too small and must be increased. Refer to the Modifying Software section of this chapter for a detailed description of modifying the graphs.

The ADDITIONAL CHANNELS frame, shown in Figure IV-13, displays Analog Input channels 48-63 which, upon test bench installation, have no instruments connected to them. When an instrument is added, follow the procedures outlined in the Adding an Instrument section of this chapter, The data collected will be displayed on the Spare Indicator channel to which the signal was connected.

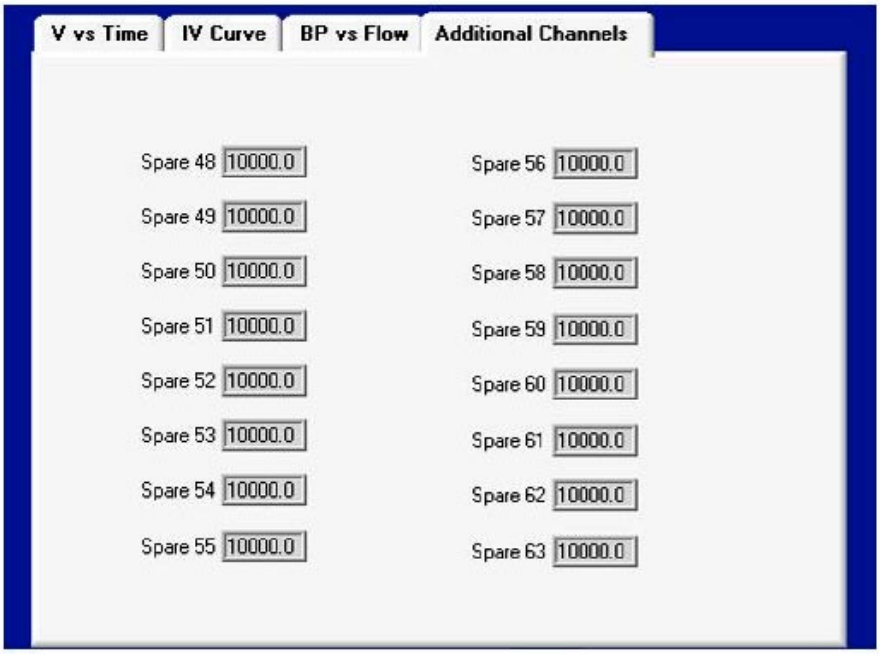


Figure IV-13. Front Panel Additional Channels Display

Error Status

If a low-level, software initiated, fault occurs, the cause of the fault will be displayed in the ERROR STATUS region at the top of the front panel (shown in Figure IV-14). The bottom, red text box displays the low-level faults and the top, yellow text box displays the warnings.

Warnings are used to indicate a condition that may lead to a fault. There is no way to hide the warnings text box. The warnings will disappear when the potentially undesirable condition has ceased.

The indication of low-level faults is latched to ensure that the test bench operator is aware that the unsafe condition occurred. After a low-level fault occurs, the system is placed in a safe state and both the error status text box and the CLEAR SAFETY FAULT button appear. The CLEAR SAFETY FAULT button must be pressed before the system can be run again. Note, this CLEAR SAFETY FAULT button is not related to the SAFETY ENABLE HARDWARE button on the front panel of the Safety Tray. The hardware SAFETY ENABLE button is used only for high-level hardware shutdowns. For a detailed description of the procedures used during shutdowns refer to the Startup and Shutdown section of this chapter.

Figure IV-14. Error Status display

2. Block Diagram

The block diagram contains a graphical depiction of the software logic that controls the test station. The block diagram for the test station contains four main sections, startup, subtasks, front panel display logic, and shutdown. Figures IV-15 and IV-16 display these sections of the block diagram.

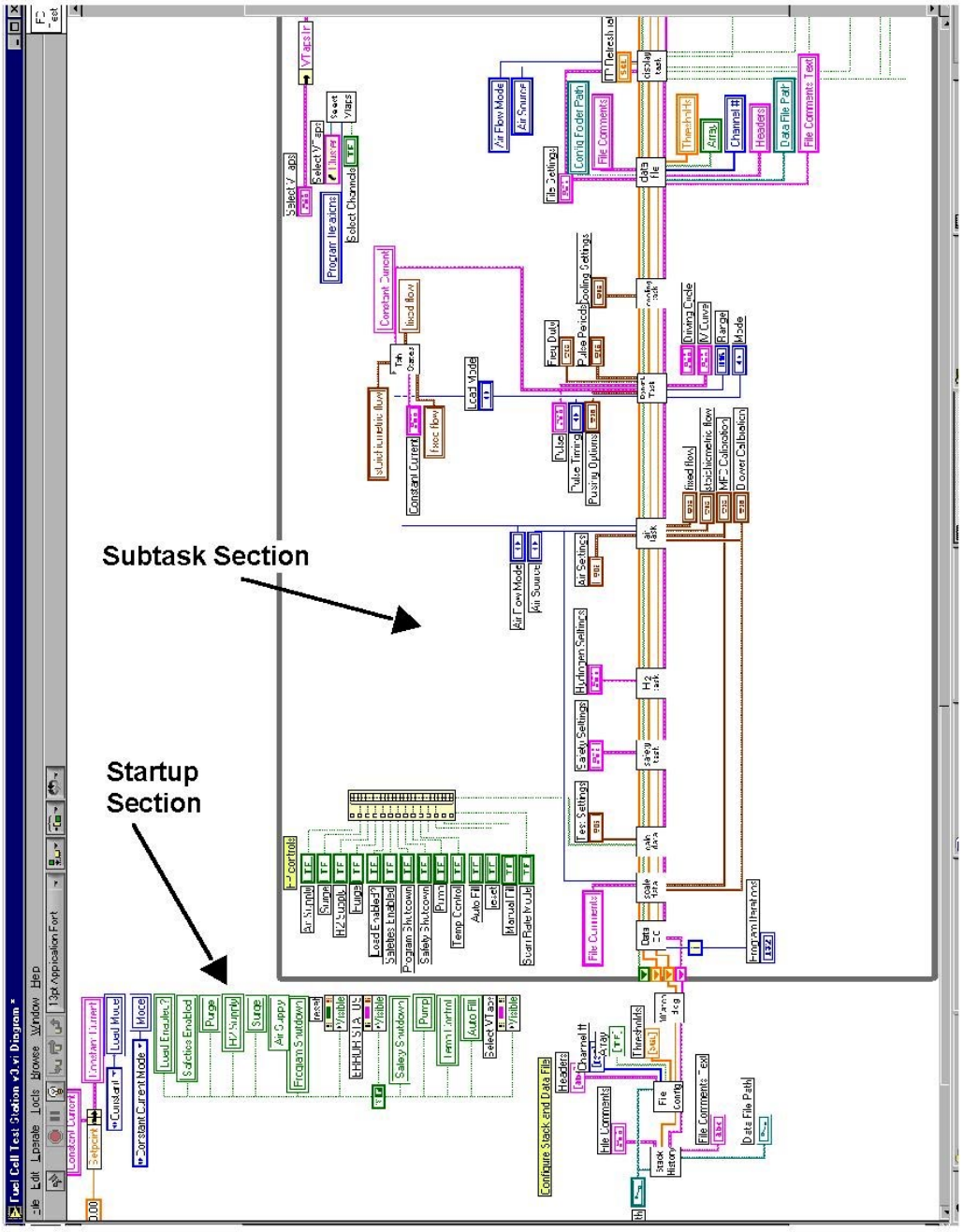


Figure IV-15. Startup and Subtask Section of the Block Diagram

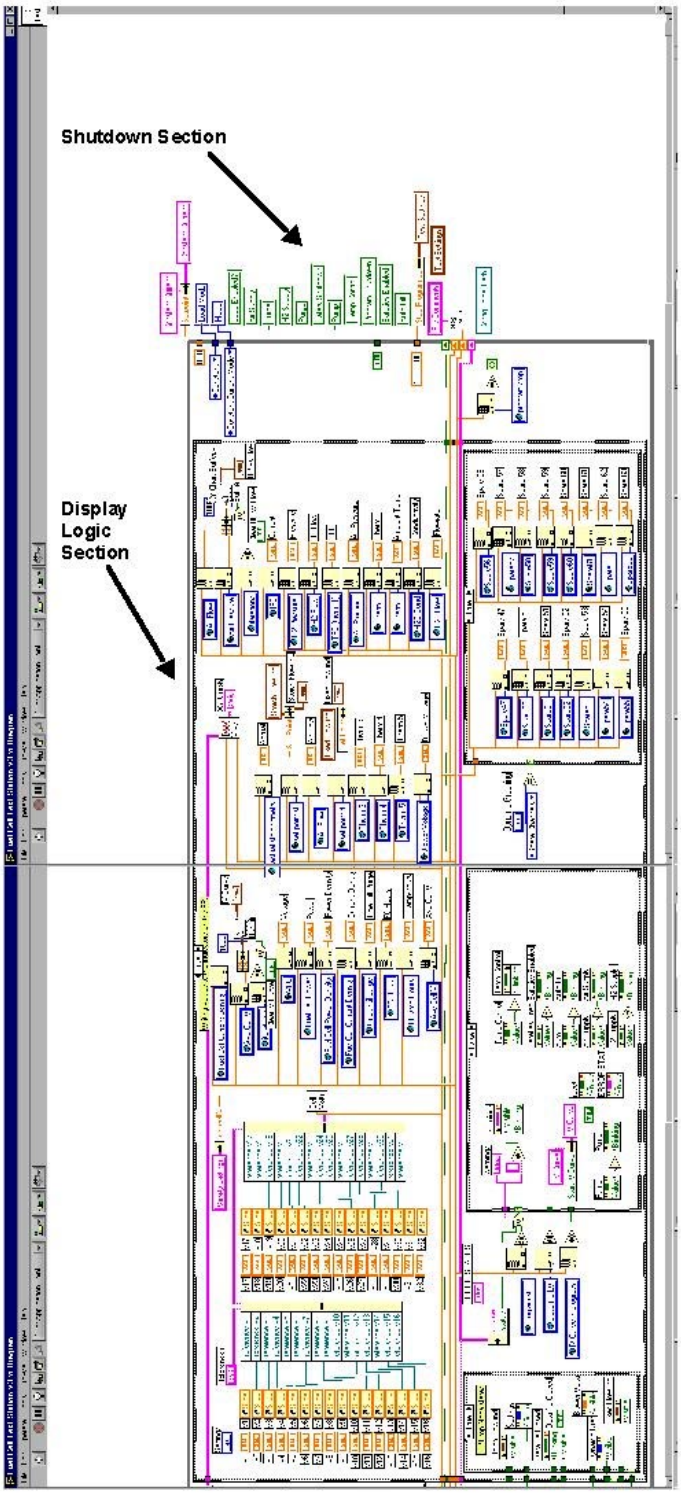

Shutdown Section
Display
Logic
Section

Figure IV-16. Display and Shutdown Section of the Block Diagram

The startup section of the block diagram, located to the left of the main while loop, is used to step the user through the startup routine when the program is first run. The startup routine consists of establishing the settings for the stack being tested, configuring the data file contents, and supplying power to the backplanes. In addition, the startup section includes the logic that initializes the front panel controls.

The subtasks section of the block diagram consists of ten sequential subroutines that perform independent tasks. These subtasks are named: DATA IO, SCALE DATA, CALCULATE DATA, SAFETY TASK, HYDROGEN TASK, AIR TASK, COOLING TASK, LOAD TASK, DATALOG, and DISPLAY TASK. Five arrays of data (ANALOG IN, DIGITAL IO, ANALOG OUT, CALCULATE DATA, and ERROR) are passed through each subtask. The subtasks read and write values to these arrays and then pass the data to the next subtask.

The DATA IO subtask is used to acquire and send data to the backplanes via the DAQ boards and signal conditioning hardware. The SCALE DATA subroutine scales the raw analog input data (0-5VDC signals) based on the instrument calibration curves. The analog input data are manipulated and stored in the CALCULATE DATA array in the CALCULATE DATA subroutine. For example, current and voltage (analog inputs) are multiplied to determine power. Current and voltage are stored in the ANALOG INPUT array, while power is stored in the CALCULATE DATA array. The SAFETY TASK is used to handle the low-level faults and warnings. This subroutine checks all of the safeties selected on the front panel and controls the error dialog. The hydrogen, air, cooling, and load subsystems are controlled in the HYDROGEN, AIR, COOLING, and LOAD subroutines. The DATALOG subtask handles the writing of all data files. Finally, the DISPLAY TASK is used to determine whether data is written to the front panel.

The FRONT PANEL DISPLAY LOGIC section of the block diagram is separated into two areas, the error handling and the indicator display. The error handling logic is located in the bottom left portion of the case structure and is responsible for changing the state of the front panel controls (which indirectly controls the hardware when these values are passed to the subtasks). The indicator display area (the rest of the logic) is used to write data to the front panel. Inputs from the user (front panel controls) are not handled in this section of the block diagram.

The shutdown section of the block diagram, located to the right of the main while loop, only executes after the front panel PROGRAM SHUTDOWN button has been pressed. The shutdown logic places all hardware in a safe state before shutting down the test station. In addition, the shutdown section includes the logic that initializes the front panel controls in preparation for the next test station startup.

B. Startup and Shutdown

The following procedures should be used when running the test station. A complete test station power-up or shutdown is used when the system has been shutdown and all AC power is disconnected from the bench. Normal startups and shutdowns occur in between tests. Refer also to the Quick Startup and Shutdown Procedures outlined in Appendix C.

Test Station Power-Up

1. Turn the UPS on.
2. While pressing the SIREN BYPASS button on the Safety Tray Panel, turn the POWER switch (also on the Safety Tray Panel) to the ON position. Release the SIREN BYPASS button.
3. Press the SAFETY ENABLE button on the tray. If one of the hardware safeties has triggered, the siren will sound and the LEDs will indicate which hardware fault has occurred. Pressing the SIREN BYPASS button will silence the siren until the SAFETY ENABLE button is pressed. Continue to troubleshoot any hardware safeties until the Safety Status LED is green.
4. Turn on the Computer and launch the LabVIEW™ test station program.
5. Connect all subsystem lines, electrical cables, VTaps and thermocouples as described in Section A of Chapter III.
6. Perform a valve line-up on the test station subsystems as follows.

! **WARNING:** Before opening any valves, either manually or remotely from the control software, the operator should have a complete understanding of what the normal system response should be. If a water, gas, or air leak is detected or any unexpected system response occurs, immediately close the valve and correct the problem.

   a. Water Circulation System
      i. Close the water reservoir drain valve.
      ii. Open the DI water supply valves.
      iii. Open the water throttle valve half way.
   b. Air System
      i. Open the air supply valve.
      ii. Position the 3-way valve to the desired MFC.
   c. Hydrogen System
      i. Close the manual supply, delivery, purge, and cylinder valves.
      ii. Open the cylinder valve and check all pressure gauge readings.
      iii. Open the delivery valve.
      iv. Vent the line by opening the high pressure vent valve.
      v. Open the hydrogen supply manual valve.
      vi. Close the hydrogen purge drum drain valve.
      vii. Close the hydrogen purge solenoid valve bypass valve.

7. The test station is ready for fuel cell testing.

Normal Startup

1. Check to make sure that the SAFETY STATUS LED is green. If the LED is red, troubleshoot the high-level faults before proceeding.
2. Start the test station program by pressing the white arrow in the top left corner of the toolbar on the front panel.
3. You will be prompted to select, through the menus, which stack you are operating. Figure IV-17 displays the dialog box for determining the stack that you want to test. Click on Stacks and scroll down the menu to either select an existing stack or "NEW STACK" for a stack that has not previously been tested.

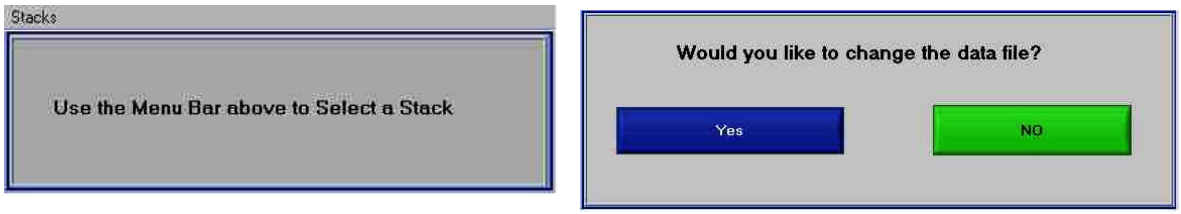


Figure IV-17. Dialog for choosing a stack to test

4. Enter the stack parameters in the dialog box displayed in Figure IV-18. These stack parameters are included in the data file.

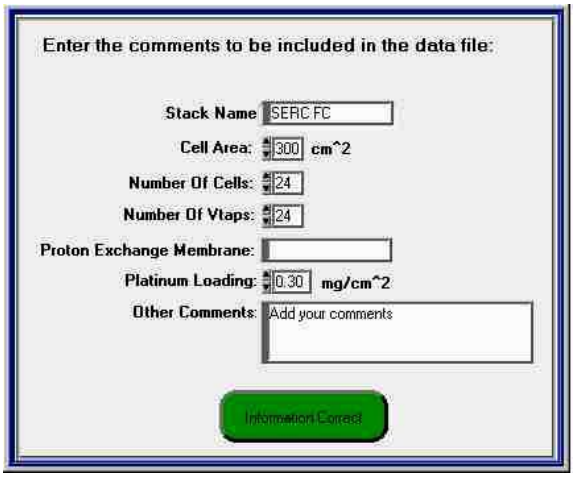

Enter the comments to be included in the data file:
Stack Name: SERC FC
Cell Area: 300 cm^2
Number Of Cells: 24
Number Of Vtaps: 24
Proton Exchange Membrane:
Platinum Loading: 0.30 mg/cm^2
Other Comments: Add your comments
Information Correct

Figure IV-18. Dialog for setting the stack parameters

5. After entering the stack parameters, a dialog box will appear to prompt you to change the data file. If you would like to change the data file, refer to the Software Modifications section of this chapter. If you will not be changing the data file, select NO. You will then be prompted to press the BACKPLANE START button. Press the BACKPLANE START button on the Safety Tray Panel and THEN press the dialog's OK button.

! **WARNING:** If you press the BACKPLANE START button after clearing out the BACKPLANE START dialog box, bad data will be written to the data file. Bad

data results because the backplanes are unpowered and data is being written to the data file (the subtask section of the block diagram is iterating).

6. The ERROR STATUS text box will indicate the last fault that occurred, usually a Manual Shutdown. Clear the software safeties by pressing the CLEAR SAFETY FAULT button in software.

WARNING: A clear distinction should be made between the SAFETY ENABLE button on the Safety Tray Panel, the SAFETY ENABLE button in software, and the CLEAR SAFETY FAULT button in software. The Safety Tray SAFETY ENABLE is used to clear high-level/hardware faults and is a physical button. The SAFETY ENABLE button in software is used tell the software that you want to safely shut the system down when a low-level software fault occurs. The CLEAR SAFETY FAULT button is a software control and is only displayed after a low-level fault occurs.

7. Enter the desired temperature and reservoir values in the COOLING settings box. Enable the reservoir AUTO FILL to fill the water system.
8. Once the reservoir and system has completed filling, turn the water pump on. Monitor flow rate and adjust the water throttle valve as necessary.
9. Open and leave open the air bleed valve on the right endplate to remove trapped air from the cooling manifold.
10. Enable temperature control by pressing the TEMPERATURE CONTROL button.
11. With the air inlet hose disconnected from the stack, select the AIR settings box and enter air source, airflow mode and surge information. Open the AIR SUPPLY and monitor airflow and inlet pressure to ensure the desired flow rate is achieved and pressure is low. Re-connect the air inlet hose.
12. Enter purge control values in the H_2 SETTINGS box. Open the H_2 SUPPLY and monitor hydrogen pressure. Refer to the Low Pressure Regulator Adjustment procedure in Chapter III if the pressure is not within desired range.
13. Manually purge the fuel cell by pressing and holding open the PURGE button for a few seconds. Cell or block voltages should increase to 800-950 mV per cell.
14. Select the SAFETY settings box and enable and enter values for the low level faults.
15. Once voltages are above the minimum cell voltage safety setpoint, enable the SAFETIES.
16. Turn on the load.
17. Enter the correct range, desired mode and limit type and value information in the LOAD SETTINGS box.
18. Press the ENABLE LOAD button.

19. Increase the load by entering the desired value into the SETPOINT control box. Cell voltages will decrease as the load on the fuel cell stack is increased.
20. Refer to Table IV-9 to verify the system parameters are within their normal range of operation.

Table IV-9. Normal Values for Test Station Operating Variables

System	Indication/Parameter	Monitored at	Normal Value/Range
Air	Setpoint stoichiometry	front panel	200-300%
	Actual stoichiometry	front panel	200-400%
	Air inlet pressure	front panel	0-50 in. WC
	Air regulator pressure	gauge	20-35 psig
Hydrogen	Cylinder regulator pressure	gauge	70-100 psig
	Low pressure regulated pressure	front panel	2-5 psig
Water	Water flow rate	front panel	1-4 liters/min.
	Temperature at fuel cell	front panel	Setpoint ± deadband
	Conductivity	front panel	< 5 μS
	Water pressure	gauge	<100 in. WC

Startup after a High-Level Fault

1. Press the SIREN BYPASS button to silence the horn.
2. Stop the Test Station program by pressing the software PROGRAM SHUTDOWN button.
3. Observe which high-level fault caused the shutdown by checking the color of the LEDs on the Safety Tray. Refer to the High-Level Faults section of the Troubleshooting chapter to handle the fault.
4. Press the SAFETY ENABLE button on the front panel of the Safety Tray.
5. If the horn goes off again, after pressing the Safety Enable button, the condition causing the high-level fault is still occurring. Continue troubleshooting the high-level fault until the siren no longer goes off after pressing the SAFETY ENABLE button.
6. Follow the Normal Startup Procedures above.

Normal Shutdown

1. When finished testing, press the software PROGRAM SHUTDOWN button.

2. A few seconds after the PROGRAM SHUTDOWN button is pressed, check to make sure that the BACKPLANE POWER LED on the Safety Tray front panel is red.
3. Turn off the load.

Test Station Power-Down

1. When finished testing, press the software PROGRAM SHUTDOWN button.
2. A few seconds after the Program Shutdown button is pressed, check to make sure that the BACKPLANE POWER LED on the Safety Tray front panel is red.
3. Close the LabVIEW™ program and turn off the computer and monitor.
4. Place the POWER switch on the front panel of the Safety Tray into the OFF position.
5. Turn off the UPS.
6. Close the hydrogen cylinder valve and hydrogen supply valve.

! **WARNING:** Although the UPS has been turned off, the UPS has battery backup and may still supply AC. Read the UPS manual thoroughly when any maintenance is completed on the UPS or the AC lines it supplies.

C. Modifying Software

Depending upon the type of tests to be conducted, the software may need to be manipulated. The following sections outline procedures for modifying software due to typical hardware changes.

! **WARNING:** Any person wishing to modify the software should first complete the tutorials included with the LabVIEW™ software and user manual and feel comfortable programming with a graphical user interface.

! **WARNING:** Be sure that the addition of any instrument will not exceed the current limit on the power supply. The amount of current produced by the power supply can be measured using a clamp-on ammeter.

1. Adding a Blower

A 24VDC or AC blower can be used as a source of air. Use the following procedure for installation and control of the air blower. Ensure that the blower has an in-line particulate filter to prevent debris from entering the fuel cell stack.

1. Perform the hardware procedure given in section III.E.
2. In software, include the desired code for controlling the blower and make sure that the global variable referenced for controlling the air supply when a blower is used (AC OUTLET # or BLOWER AIR SUPPLY) is correct.
3. On the front panel of the main test station program, select BLOWER as the AIR SOURCE. The blower is currently setup to send a fixed voltage when the supply

solenoid is first opened. The voltage to the blower then increases or decreases depending upon the requested airflow and the airflow being measured.

4. Set the value of the fixed flow voltage.
5. Set the calibration for the airflow transducer.
6. Disconnect the air blower from the fuel cell.
7. Test the blower with these new settings.
8. When you feel confident that the blower is working properly, connect the blower to the fuel cell.

2. Switching Air Mass Flow Controllers

Two mass flow controllers 0-20 slm and 0-200 slm are used to deliver air to the stack. If the stack will be operated consistently below 20 slm, it is recommended that the 20 slm mass flow controller (on the bottom) be put in service. To change which mass flow controller is used to deliver air to the stack:

1. Follow hardware procedures given in section III.D.
2. Change the calibration in AIR settings control tab located on the front panel (see the Air System in section IV.A.1). The air mass flow controller calibration is set as a linear equation, described on the front panel. The maximum airflow represents the x variable, the maximum control voltage signal represents the y variable and the slope is represented as the maximum voltage signal divided by the full scale flow. For example, if the mass flow controller is 200 slm and requires a 5 VDC signal to deliver 200 slm, the slope (m value entered on the front panel) should be 5 volts/200 slm, or 0.025 volts/slm. The calibration on the front panel scales both the input and output signals to and from the mass flow controller. Neither mass flow controller should require a non-zero offset; however, the software is capable of including an offset if desired.
3. Set the fixed flow rate to half of the MFCs full range.
4. Open the AIR SUPPLY SOLENOID.
5. Check that the analog output to the MFC is approximately 2.5V.
6. Close the AIR SUPPLY SOLENOID and reconnect the air inlet line to the fuel cell.

3. Manipulating Data Files

The standard data file (not the IV curve data file) is controlled using a dialog when the test station program starts up. To change the data file use the following steps:

1. Start the test station program.
2. After selecting which stack is to be tested, you will see the prompt displayed in Figure IV-17. Select the blue YES button.

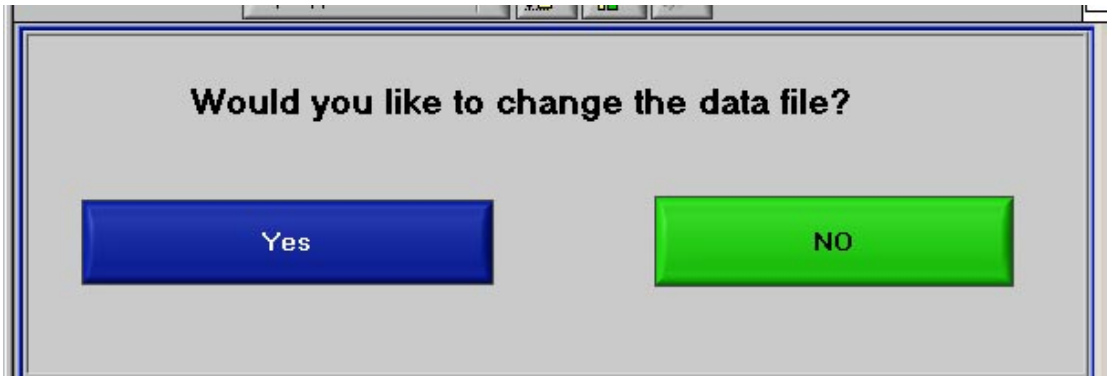


Figure IV-17. Data File Configuration Dialog

3. The data file contents dialog, displayed in Figure IV-18, should appear.

   The data file contents are presented in four columns. The first column contains the HEADERS, which are placed in the data file as a row of column headers following the stack comments. Any alphanumeric text string can be used as a header. The second column, ARRAY CHANNEL #, is used to locate the data in the array. The third column is used to specify which array, calculated data, or analog input the data are stored in. The last column specifies the FILE WRITE THRESHOLD. If the data have changed by more than the set threshold since the last data file write, new values will be written to the data file.

   For example: If you would like the operating temperature to be displayed in the data file, enter the name of the header (TFC) in the HEADER column. In the ARRAY CHANNEL # column enter the channel number corresponding to the thermocouple port that the thermocouple is plugged into. The thermocouple data is stored in the ANALOG INPUT array so the ARRAY direction should be pointed to ANALOG INPUT. Finally, the threshold, say 1°C, is entered.

   With this information selected, the data file should contain the stack comments, followed by the column headers. The first and second columns of data will contain the time of day that the data were recorded to the data file. The next columns will contain the cell voltage data. The data chosen in the contents dialog will follow the cell voltages.

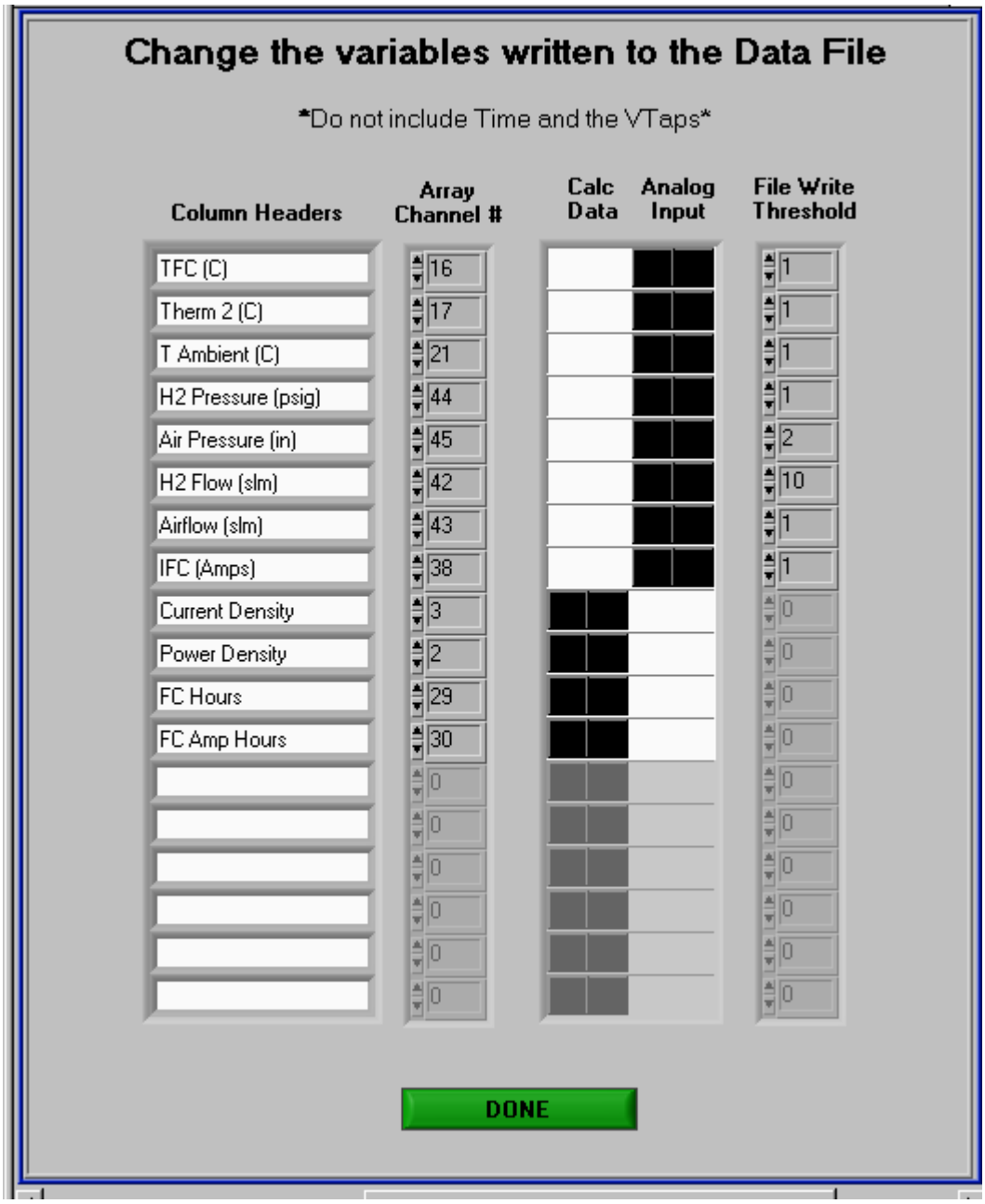

Change the variables written to the Data File
Do not include Time and the VTaps
Column Headers
Array Channel #
Calc Data
Analog Input
File Write Threshold
TFC (C) 16 1
Therm 2 (C) 17 1
T Ambient (C) 21 1
H2 Pressure (psig) 44 1
Air Pressure (in) 45 2
H2 Flow (slm) 42 10
Airflow (slm) 43 1
IFC (Amps) 38 1
Current Density 3 0
Power Density 2 0
FC Hours 29 0
FC Amp Hours 30 0
0
DONE

Figure IV-18. Dialog for Selecting the Data File Contents

When the file contents are set, press the DONE button.

4. Connecting a New Transducer

To add a new transducer to the test station, complete the following tasks.

1. Connect the transducer power supply to the appropriate bus: 120 VAC, 24 VDC or ± 15 VDC.

2. Connect the analog output of the transducer to the desired spare channel on one of the analog input backplanes and plug in the appropriate 5B analog signal-conditioning module.
3. In software, open the SCALE DATA subroutine.
4. Add the appropriate scaling factors for the transducer, using the SPARE CHANNEL # global variable for the channel number that the instrument is connected to.
5. Run the test station software.
6. Add the new instrument to the data file following the MANIPULATING DATA FILES procedures provided in this section.
7. On the ADDITIONAL CHANNELS frame of the DYNAMIC GRAPHING tab control, the scaled value produced by the transducer should be displayed on the appropriate indicator.
8. It is not recommended that you change the name of the channel from SPARE #. Changing these names would eventually cause the user to forget which channels correspond to which indicators without looking at the code. To help the user remember what the data represents, when the program is not running place a text note next to the indicator describing the data.

5. Modifying the Graphs

To change the data displayed in either the BP VS FLOW graph or the IV CURVE:

1. Open the Block Diagram for the test station software.
2. Find the area of the code, in the display section, that looks like the code shown in Figure IV-19 (for the IV curve graph).

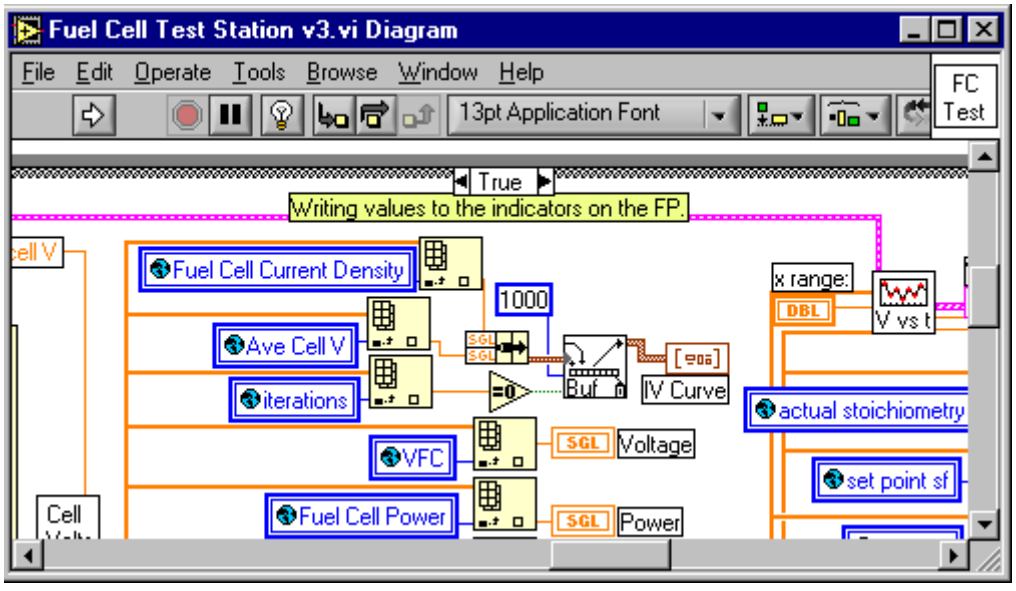


Figure IV-19. Modifying the IV Curve Graph

3. The first value supplied to the bundled cluster is the X value. The second value supplied to the bundled cluster is the Y value. Change the global variable references to the desired channels for both the X and Y variables.
4. Open the Front Panel of the test station software.
5. Rename the x and y axes to reflect the new variable names.
6. Rescale the x and y axes as needed.

Chapter V: Troubleshooting

The purpose of this chapter is to help test station users identify and correct common problems that may occur in using the test station.

A. High-Level Faults

Any high-level/software independent fault (from the hydrogen detector, smoke alarms, or ventilation flow transducer), when triggered will cause a loss of 24VDC and 5VDC power. Loss of power will result in all hardware being shut down and placed in a safe state. The LEDs on the front panel of the Safety Tray indicate which fault occurred. If the hydrogen detector senses a significant leak (≥1% hydrogen in air), the H_2, SMOKE, and FAN LEDs will turn red. If one of the two smoke detectors detects smoke, the SMOKE and FAN LEDS will turn red. If the ventilation flow transducer does not detect an acceptable pressure differential between the hood and the air exhaust trough, the FAN LED will turn red.

1. Hydrogen Leaks

The hydrogen detector consists of a transmitter and sensor. The sensor, mounted in the hood, detects the concentration of hydrogen in air. Use the following procedures if a hydrogen alarm is triggered:

1. Close the hydrogen cylinder valve.
2. Look at the hydrogen detector digital display and determine the percentage of hydrogen in air being detected in the hood.
3. If the hydrogen in air percentage is greater than 2%, leave the room and notify facility safety personnel.
4. If the percentage is between 0.5% and 2%, complete a visual inspection of the hydrogen plumbing following the procedures outlined in the Leak Check section of the Maintenance chapter. You will not be able to restart the test station and pressurize the system downstream of the H_2 supply solenoid until the concentration decreases below 0.5%.
5. If the percentage is less than 0.5%, leak check the hydrogen plumbing following the procedures outlined in the Leak Check section of the Maintenance chapter. You may need to complete several iterations of pressurizing and depressurizing the system until the percentage of hydrogen in air is consistently below 0.5% while the system is under pressure.

2. Smoke Alarms

The two smoke alarms, connected in tandem, will alarm until smoke is no longer detected. If the smoke alarms are sounding, leave the building and notify appropriate personnel of the potential hazard. If the smoke alarms are not sounding, investigate the possible sources of smoke.

3. Fan Alarm

The FAN ALARM uses a differential pressure transducer (referred to elsewhere in this manual as the ventilation flow transducer) to detect the pressure differential between the hood and the exhaust trough in the floor. If the pressure differential is not satisfactory, the alarm will trigger. Use the following procedures to troubleshoot a fan alarm:

1. Check to ensure that the room ventilation system is running.
2. Inspect the hood exhaust line for any obstructions.

B. Clearing Safety Faults

After a High-Level fault has occurred, the operator should follow the guidelines presented above to determine which fault occurred and why. After the unsafe condition has passed, follow the Startup After a High-Level Fault procedures in Section IV.B.

C. Software Debugging

There are two types of software debugging to consider, code and hardware. When debugging new or modified code, follow the guidelines provided by National Instruments. When debugging hardware problems, where the software is functioning but may not be executing as intended, you need to differentiate between software and hardware faults. In the block diagram, place a probe upstream of the Data IO subroutine, on the array that contains the data you are investigating.

For example, if the hydrogen supply solenoid is not opening when you press the H_2 SUPPLY button on the front panel:

1. Place a probe on the DIGITAL IO array.
2. On the probe, select the channel that contains the H_2 SUPPLY data.
3. Change the state of the solenoid and check to see that the digital output from the software changes.
4. If the probe shows a change in state of the supply solenoid, you now know that the software is not the root of the problem.
5. Look at the digital backplane and make sure the light next to the module that controls the supply solenoid is changing state when the H_2 SUPPLY button is pressed on the front panel.
6. If the light on the backplane is changing states, you are now dealing with a problem in the connection between the backplane and the solenoid valve or the solenoid valve itself. If the light is not responding, the problem lies somewhere in the DAQ hardware.

These general procedures can be used regardless of the type of signal being tested. For analog input data, probe the value coming into the program and compare it to the value at the backplane. For analog output data, probe the value being sent from the software and

compare that value to the value that should be sent based on the software logic and to the value actually being sent through the backplanes.

! **WARNING:** Before making significant changes to the hardware, such as removing components that are believed to have failed, always check that the instruments are powered up and that the proper signals are being sent to and from the instruments.

D. Low-Level Faults

There are four low-level software initiated faults: low cell voltage, operating temperature, hydrogen pressure, and water reservoir fill state. All low-level faults result in a software controlled shutdown that places the hardware in a safe state, leaves the backplanes powered, and keeps the test station program running.

- If the lowest cell voltage falls below the minimum cell voltage (set in the Safety Settings), a shutdown will occur and the ERROR STATUS will display a LOW CELL VOLTAGE fault. To determine why a particular cell voltage is performing poorly, refer to the Fuel Cell Faults section of this chapter.
- The operating temperature setpoint, measured where cooling water leaves the power section, is set in the COOLING SETTINGS. The temperature at which a fault occurs is set in the SAFETY SETTINGS. If the operating temperature exceeds the fault temperature setpoint, a low-level fault occurs.
- The hydrogen pressure must always be within the range selected. If the pressure falls outside of the range a fault will be triggered.
- The water reservoir will be automatically filled if the AUTOFILL button is selected. If the reservoir fills for too long or too often a RESERVOIR FILL fault will occur.

Table V-1 describes some of the possible reasons that a low-level fault might occur and what corrective action(s) should be taken. If a fault shutdown does not occur when a known fault condition exists, ensure the fault is selected in the SAFETY SETTINGS and the SAFETY ENABLED button is selected. If both are selected, use the SOFTWARE DEBUGGING procedures to verify the analog and digital data are being processed properly.

Table V-1. Troubleshooting a Low-Level Fault

Fault	Possible Reasons	Corrective Action
Low Cell Voltage		• Refer to the Fuel Cell Faults section of this chapter
High Fuel Cell Temperature	Stack is producing more heat than can be removed by the cooling system.	• Check that the fault setpoint temperature is not set too low. Usually the stack should run near 60°C and shut down near 65°C. • Make sure the heat exchanger fans are on and heaters are off.
	Thermocouple reading incorrect.	• Make sure operating temperature thermocouple is plugged into the Electrical Panel. • Make sure the analog input signal is being read in and scaled properly.
High Hydrogen Pressure	Pressure Regulator set too high.	• Compare the low-pressure regulator setpoint pressure to the Maximum hydrogen pressure Safety Setting and adjust the delivery pressure if necessary.
	Transducer value incorrect	• Make sure the analog input signal is being read in and scaled properly.
Low Hydrogen Pressure	Empty Cylinder	• Check the cylinder pressure and exchange if pressure < 100 psig. • If the cylinder pressure is above 100 psig but the delivery pressure is below 30 psig increase the cylinder delivery pressure to 60 psig.
	HYDROGEN SUPPLY SOLENOID Closed	• Open the HYDROGEN SUPPLY SOLENOID. • Toggle the HYDROGEN SUPPLY SOLENOID for proper response.

	Transducer value incorrect	• Make sure the analog input signal is being read in and scaled properly.
High water conductivity	Poor supply water quality	• Check the water quality of the water being supplied to the test station and correct any problems
	Conductivity indication > 10 μS on front panel	• Drain and refill water system • Replace deionization cartridge according to maintenance procedure
Reservoir Fill	Reservoir filling too often	• Check for water leaks and ensure the reservoir drain valve is closed. • Check the fuel cell air inlet line between the pressure transducer and the stack. If this line is full of water there may be a cross-leak in the humidification section of the stack. Refer to the Fuel Cell Faults section of this chapter for further details.
	Reservoir fills for too long	• Make sure the RESERVOIR FILL TIME (COOLING SETTINGS) is not greater than the FILLS NO LONGER THAN _ MINUTES (SAFETY SETTINGS) setpoint. • Drain the reservoir. Compare the digital output value to the FILL SOLENOID with the software output and make sure the FILL SOLENOID is open for time intended by software.
	Float Switch not working	• Use the Software Debugging procedures, in this chapter, to determine if the float switch is working properly.

E. Fuel Cell Faults

Fuel cell faults can present themselves in numerous ways. From anode flooding to cross-leaks, there are a number of reasons a stack may perform poorly either temporarily or permanently.

1. Troubleshooting

The operator should continuously monitor fuel cell stack performance during experimental testing. Poor performance is typically defined by relatively low cell voltage at a given current density. The more the system parameters (load, air stoichiometry, purge frequency and duration, etc.) are changed, the more likely an operational problem will occur. A summary of the symptoms that may be observed during stack operation is provided in Table V-2. The symptoms are used to identify fuel cell problems and thus help to determine the possible root causes of the problem.

Table V-2. Troubleshooting Fuel Cell Stack Failures

Problem	Symptom	Root Cause
Anode flooding	Voltage decreases during purge and recovers immediately after purge	• Hydrogen delivery system can not provide enough flow during purge. • Inadequate purge duration and period.
	Unusually wet purge	• broken separator or cooling plate
	After purge, voltage recovers, then decays after a period of time	• Inadequate purge duration and period
	Water leaks from any of the bottom four stack bolts	• Loose stack bolts, broken separator or cooling plate
Cathode flooding	Voltage rises sharply w/ air surge	• Inadequate air stoichiometry • loss of GDM hydrophobicity
	Voltages not stable at normal air stoichiometries (250-300%)	• Incorrect Airflow Source calibration,
	Unusually wet air exhaust	• Broken separator or cooling plate
	Water leaks from stack or stack bolts	• Loose stack bolts
Humidification cross-leak	High and/or fluctuating air pressure	• Torn humidification membrane

	Water collecting in the Air Inlet line when the stack is not being operated.	• Torn humidification membrane
Power Section cross-leak	Cell does not pass cross-leak check	• Hole or tear in membrane
	Voltage rises when H_2 pressure is removed	• Porous or broken separator/cooling plates
	Sniffer indicates H_2 in air exhaust	• Hole or tear in membrane • Porous or broken separator/cooling plates • Loose stack bolts
MEA damage	Lack of above symptoms	• Catalyst contamination • Voltage forced above 1.8 V/cell • Water connected to Air or H_2 fittings
Restricted airflow	voltage rises sharply with air surge with out signs of flooding	• Mechanical blockage

2. Cross Leak Check

To determine if a cell in the stack has developed a cross-leak due to a puncture in the membrane, pervious separator/cooling plates, or loose stack bolts, use the following procedures:

1. Place the load at open circuit by setting the load to 0 Amps. Open the Load Contactor.
2. Open the HYDROGEN SUPPLY SOLENOID and supply at least 10 slm air.
3. Wait until the cell voltages are relatively stable.
4. Use the hydrogen detector to measure the amount of hydrogen present in the air exhaust (indication of the presence of hydrogen is satisfactory).
5. Remove the air supply by disconnecting the hose from the air inlet fitting.
6. Observe the cell voltages over time.

If a cell voltage rapidly decays after removal of the air supply, observe which cell crashes first. The first cell to crash is usually the cell that has a punctured membrane or is near a cracked graphite plate. A rapid decrease in cell voltage is a sign of a significant cross-leak. If a cell voltage holds strong initially but begins to degrade within 30 seconds, a lesser but still significant leak may be present. If all cell voltages stay above 800 mV for longer than 30 seconds, the cells do not have a significant cross leak.

!

WARNING: Notify the Schatz Energy Research Center if a cross leak is suspected.

Chapter VI: System Maintenance

The purpose of this chapter is to explain routine preventative maintenance procedures that should be carried out in order to avoid test station malfunctions and ensure a long, safe operating lifespan for the test station.

A. Air, Hydrogen and Water Systems Maintenance

Common maintenance tasks for all three subsystems include visual inspections, pressure relief valve setpoint checks, and system leak checks. Other procedures are for specific tasks such as deionization cartridge changeout, hydrogen filter cleaning and replacement, and hydrogen vent line purging.

1. Visual Inspection

The operator should make a periodic visual inspection of all system components including gauges, hoses and vent line exits. The components should be inspected for cleanliness and integrity in order to identify potential failures. Vent line inspection is extremely important during the winter months to ensure ice or snow does not block the outlet of the vent lines and inhibit gas flow.

2. Pressure Relief Devices

The subsystem pressure relief devices (PRDs) are checked to assure the setpoints are maintained and the valves have not become stuck in their normally closed position. As listed in Table VI-1, there are five spring-loaded PRDs, four of which require checking; the hydrogen medium pressure, the air medium and low pressure and the water low pressure relief valves. The hydrogen low pressure relief valve is not adjustable and does not require checking. The maintenance interval for setpoint checks is once a year.

Table VI-1. Pressure Relief Valve Setpoints

System	*Relief*	*Setpoint*	*Units*	*Notes*
Hydrogen	medium pressure	150	psig	
Hydrogen	low pressure	9	psig	Not adjustable
Air	medium pressure	55	psig	
Air	low pressure	150	in. WC	
Water	low pressure	120	in. WC	

A pressure test rig which includes a compressed gas cylinder, cylinder regulator and hose, a pressure gauge with the appropriate pressure range, and a vent valve is required to test the PRDs. The test station must be shutdown and the systems depressurized or drained. The PRDs should be removed from test station. The General Pressure Relief Valve Procedure outlines the necessary steps to complete the task.

General PRD testing procedure

1. Close the system isolation valve for the appropriate subsystem.
2. Depressurize or drain the system until pressure indicates 0 psig where the PRD is installed.
3. Remove the tee that houses the relief valve from the system by loosening the Swagelok® fittings each side of the tee.
4. Set-up a compressed nitrogen test rig which includes a high pressure nitrogen cylinder, regulator and hose, a pressure gauge with the appropriate pressure range, and a vent valve.
5. Connect one open end of the tee to the test hose, cap the other open end, and secure the hose or relief valve to a stationary object with straps.
6. Slowly raise pressure by adjusting the regulator until gas relieves from the valve and note the lifting pressure. Lower the regulator delivery pressure to stop the valve from relieving.
7. If the lifting pressure is at the desired setpoint, go to next step. If the lifting pressure is not within the setpoint range (1 psig or 10 in. WC as appropriate), the valve requires adjustment. Depressurize the test hose prior to making an adjustment. Refer to the appropriate component specification sheet for a diagram of the PRD and adjust the setpoint as follows:
   - Loosen the locking screw with hex head wrench.
   - Turn the adjusting screw clockwise to increase the setpoint or counter clockwise to decrease the setpoint.
   - Tighten the locking screw and go to step 6 above and retest.
   - Continue to make adjustments until the setpoint is reached.
8. Remove the PRD tee from the test hose and reinstall into system.
9. Tighten the Swagelok® nuts on each side of the tee.
10. Restore the system to normal and leak check all fittings that were loosened.

3. Leak Checks

The most important maintenance task to be performed, especially on the hydrogen plumbing, is periodic leak checking. Leak checks should be performed every 3 months and after any system maintenance, whether corrective or preventive. System operators can perform leak tests with a portable gas detector or “Snoop”-type leak-checking fluid. Leak checks using these methods can be performed with the system running and fully pressurized. Another method for leak checking is the pressure drop test. With the system shut down and pressurized, record all pressure gauge and pressure transducer values. After 1 hour (or longer if feasible), record the pressures again and compare them to the previous values. A decrease in pressure will indicate a leak and its approximate location in the system. Snoop or a portable gas detector can then be used to locate the leak precisely. If the leak is from a component or section of the system that cannot be fixed or

retightened, that section or component must be replaced. The system must be depressurized before the leak can be fixed.

! ***Note: Never attempt to tighten a leaky fitting while under pressure!***

Most likely the leak is from a loose Swagelok® fitting. As stated in the Swagelok® Tube Fitter's Manual, these connections can be disconnected and re-tightened many times. The same reliable, leak-proof seal can be obtained every time the connection is remade. To tighten the fitting apply the appropriate size wrench to the Swagelok® nut and the fitting it screws on to. While holding the fitting stationary, turn the Swagelok® nut clockwise until tight. Pressurize the system and recheck for a leak.

4. Valve and Regulator Cross-Leak Checks

A valve or regulator cross leak can cause improper system operation. While performing routine operation and maintenance procedures, the operator should closely monitor system response to valve manipulations and watch for symptoms that may indicate a cross leak problem. Early detection of a cross leak will allow repair and/or replacement of the defective part before further damage occurs.

5. Deionization Cartridge Changeout

In order to inspect and/or replace the resin cartridge, the test station must be shut down and the water circulation system isolated and depressurized. Prior to changing out the cartridge, perform all the corrective actions presented in the troubleshooting section.

The procedure is as follows:

1. Ensure the test station is shut down.
2. Close the blue-handled water supply valve located at the back top-center of the test station.
3. Open the water systems drain valve located under the water reservoir and connect the cooling water inlet hose to the quick-connect under the reservoir.
4. Once the system is drained, place a bucket under the blue cartridge housing. While supporting the weight of water-filled sump, loosen the sump by turning counterclockwise.
5. Remove the sump carefully so as not to spill water onto the components or wires below. Dispose of the water and cartridge and rinse the sump clean. The resin cartridge is not hazardous and can be disposed in a regular waste receptacle.
6. Remove O-ring/gasket from sump and wipe groove and O-ring/gasket clean. Place O-ring/gasket back in place and press O-ring down into the groove with two fingers. **Caution**: If O-ring/gasket appears damaged or crimped it should be replaced.
7. Place a new cartridge in the sump and screw the sump onto the cap until hand tight. **Caution:** Do not overtighten.
8. Close the drain valve, reconnect the hose to the fuel cell, and open the water supply valve.

9. Start the station software and open the reservoir fill solenoid valve.
10. Once full, start the circulation pump to remove air from the system.
11. Check the cartridge housing for water leaks and tighten the sump if necessary.
12. Monitor water conductivity.

6. Hydrogen Filter Inspection

The hydrogen filter removes debris from the gas stream prior to entering the low pressure regulator. Annual inspection of the filter is required to determine if cleaning or replacement of the filter element is necessary.

Depressurize the hydrogen plumbing as follows:

1. Close the hydrogen cylinder valve.
2. Open the delivery and supply manual valves.
3. Open the hydrogen vent valve and ensure pressure on the regulator delivery pressure gauge decreases to 0 psig.
4. Follow the MAINTENANCE procedure on the filter specification sheet provided in the Component Spec Sheets binder in Appendix B.
5. Close the delivery, supply manual and hydrogen vent valves when maintenance is completed.

7. Hydrogen Vent Line Purging

The high pressure vent line exits the lab and vents gas outside the building. During the winter months it is possible for ice to form and plug the vent line outlet fitting. In order to identify a blocked vent line, it is recommended that the vent valve be periodically opened and closed to purge hydrogen through the vent line and remove any ice. When purging, ensure that gas flow is heard exiting the vent line. At a minimum, the vent line should be purged before every test station start-up during the winter months.

B. Safety System

The test station safety system includes several components that require periodic maintenance. Procedures are as follows.

1. Smoke Alarms

The smoke alarms have procedures, detailed on pages 5 and 6 of the specification sheets, for cleaning and maintaining the alarms. It is recommended that the alarms be tested annually with the test bench running. To test the alarm:

1. Use the appropriate Startup Procedures outlined in Chapter IV to get the test station online.

2. Use the Testing Alarm procedures on page 4 in the Smoke Alarm manual to trigger the smoke alarm.
3. After the smoke alarm triggers, a hardware shutdown should occur and the Safety Tray siren should alarm.
4. Silence the alarm by pressing the SIREN BYPASS button on the Safety Tray front panel.
5. When the Smoke alarm stops triggering, press the SAFETY ENABLE button on the front panel of the Safety Tray.
6. Press the BACKPLANE START button on the front panel of the Safety Tray.
7. You are now ready to resume normal fuel cell testing.

2. Ventilation Flow Transducer

The Ventilation Flow Transducer will normally require no special maintenance and should not be serviced. It is recommended that the transducer be tested annually with the test bench running. To test the transducer:

1. Use the appropriate Startup Procedures outlined in Chapter IV to get the test station online.
2. Disconnect the low pressure hose from the ventilation flow switch.
3. After the switch triggers, a hardware shutdown should occur and the Safety Tray siren should alarm.
4. Silence the alarm by pressing the SIREN BYPASS button on the Safety Tray front panel.
5. Reconnect the low pressure hose to the ventilation flow switch.
6. When the switch stops triggering, press the SAFETY ENABLE button on the front panel of the Safety Tray.
7. Press the BACKPLANE START button on the front panel of the Safety Tray.
8. You are now ready to resume normal fuel cell testing.

3. Hydrogen Detector

The manufacturers of the hydrogen detector recommend weekly tests of the hydrogen sensor. To test the sensor on a weekly basis refer to page 33 of the sensor manual. It is also recommended that the sensor be tested with the Safety System every year. To test the sensor with the Safety System:

1. Use the appropriate Startup Procedures outlined in Chapter IV to get the test station online.
2. Remove the hydrogen inlet line from the fuel cell stack.
3. Place the hydrogen inlet line next to the sensor.

4. Close the supply manual valve upstream of the supply solenoid.
5. Open the supply solenoid.
6. Slightly crack the manual valve until gas flows and the sensor responds to the increased hydrogen concentration.
7. After the transmitter triggers, a hardware shutdown should occur and the Safety Tray siren should alarm.
8. Close the manual valve.
9. Silence the alarm by pressing the SIREN BYPASS button on the Safety Tray front panel.
10. Close the solenoid valve and open the manual valve.
11. Reconnect the hydrogen inlet line to the stack.
12. When the transmitter stops triggering, press the SAFETY ENABLE button on the front panel of the Safety Tray.
13. Press the BACKPLANE START button on the front panel of the Safety Tray.
14. You are now ready to resume normal fuel cell testing.

C. Transducer Calibrations

To ensure that all transducers are properly maintained and calibrated, follow the specifications given for each instrument in the manufacturer's literature.

D. Control and Monitoring Hardware

The control and monitoring hardware should not require special procedures for maintenance. To ensure that the equipment functions properly, use the following guideline.

1. Check Integrity and Condition of Visible Wiring

Periodically, a visual inspection should be made of any electrical wiring that can be easily accessed. Check for damage to wire insulation and gently tug on the wires to make sure they are not loose.

2. Keep Components Clean

Periodically all easily accessed electrical components should be inspected and cleaned as needed. Do not allow dirt, dust and debris to accumulate around electrical components. Vacuum these areas as needed.

3. Uninterruptible Power Supply (UPS)

The UPS unit will normally require no special maintenance. However, if for any reason it is taken out of service for an extended period, it should be stored unplugged. During out-of-service storage, the UPS should be plugged in once every three months and allowed to recharge for 4 to 6 hours to maintain the batteries' charge elasticity. See page 7 in Tripp-Lite UPS owner's manual.

Note that to avoid a safety shutdown, the SERC electrical control panel should remain plugged into the UPS and the UPS should remain plugged into the wall outlet at all times.

Chapter VII: Safety

In addition to the safety information given in this manual, please also read the safety information provided in the manufacturers' literature provided with the test station as Appendix B to this manual.

We also provide a list of recommended reading material at the end of this chapter that covers hydrogen system safety, as well as proper hydrogen gas system design and operation.

A. Safety Orientation

This chapter addresses safety issues that all personnel working with the test station need to be aware of. The system, while designed for maximum safety and fully compliant with all applicable safety codes and regulations, can be hazardous if not operated correctly. The primary potential hazards associated with the test station include:

- high-pressure gas accidents,
- fire, and
- electric shock.

After studying this section of the Operations and Maintenance Manual, system operators should understand these hazards and be prepared to respond to any foreseeable hazardous situation that may arise in a manner that will protect personnel in the vicinity while also avoiding or minimizing harm to the facility and equipment.

! **WARNING:** Never work at the fuel cell test station alone. At least two people should be in the room at all times when the test station is operating. Only authorized, trained personnel should operate the fuel cell test station.

B. Test Station Safety Features

The fuel cell test station is equipped with numerous safety features to ensure safe system operation. These features include: smoke alarms, hydrogen gas alarm, ventilation flow alarm, watchdog timer, pressure relief devices, emergency shutdown button, and intrinsic safety features (i.e. if electrical power is lost, all relays, solenoid valves and power contactors will revert to a safe condition).

Selected safety features are discussed below. Hardware and software safety features, including high level and low level system shutdowns, are also discussed in the Safety Control System section of Chapter I and in Chapter V, Troubleshooting.

Smoke Alarms

Smoke alarms are mounted in the vent hood and on the wall of the test station room. They are AC powered with an internal battery backup. If an alarm is set off, they will give off both audible and visual alarm signals, and will initiate a high level emergency shutdown of the fuel cell test station. The smoke alarm is discussed further in Chapter V, Troubleshooting.

Hydrogen Gas Alarm

A hydrogen gas detector is located in the vent hood of the fuel cell test station. If hydrogen gas is detected at a concentration of 1% by volume or more (25% of the lower flammable limit of hydrogen in air) the hydrogen alarm will initiate a high level shutdown of the fuel cell test station and an audible alarm. The hydrogen gas alarm is discussed further in Chapter V, Troubleshooting.

Ventilation Flow Alarm

A differential pressure flow transducer (diaphragm switch) will indicate if there is a loss of ventilation airflow for the test station area. If a loss of ventilation airflow occurs, the diaphragm switch will initiate a high level shutdown of the fuel cell test station and an audible alarm. The ventilation flow alarm is discussed further in Chapter V, Troubleshooting.

Watchdog Timer

The control system for the fuel cell test station is equipped with a watchdog timer. If the computer locks up or a software error occurs that inhibits proper operation of the system control functions, the watchdog timer will cut 5 VDC power to the backplanes and 24 VDC power to the test station components. This will close all solenoid valves, turn off all test station components, and place the test station in a safe state. The watchdog timer is discussed further in the Safety Control System section of Chapter I.

1. Properties of Hydrogen Gas

Hydrogen has an undeserved reputation as a highly dangerous substance. In reality, in some situations it can be safer to work with hydrogen than with other fuels we commonly use (such as gasoline, methane/natural gas and propane); in other situations it can be more hazardous. Therefore, prior to operating the system, personnel should have a basic understanding of hydrogen gas properties and associated hazards.

The principal hazard presented by hydrogen systems is the uncontrolled combustion of accidentally released hydrogen. For hydrogen to combust, two additional elements are required: an oxidizer and a source of ignition. Hydrogen is combustible over a wide range of concentrations in air, and a variety of common physical processes (open flames, hot surfaces, friction, electrical spark, static discharge) can serve as sources of ignition. Some important characteristics of hydrogen are discussed in more detail below, and Table VII-1 compares some of hydrogen's physical properties with those of methane. The NFPA 704 Rating for hydrogen gas is: **Health** 0 **Fire** 4 **Reactivity** 0 **Special** None

Table VII-1. Some Physical Properties of Hydrogen and Methane

	Hydrogen	Methane
Autoignition temperature	520º C	630°C
Heat of combustion (lower heating value)	120 kJ/kg	50 kJ/kg
Lower flammable limit (in air)	4% by volume	5.3% by volume
Upper flammable limit (in air)	75% by volume	17% by volume
Stoichiometric mixture (in air)	29.5% by volume	9.5% by volume
Density (20C, 100kPa)	0.0827 kg/m^3	0.6594 kg/m^3
Diffusion coefficient (in air)	0.61 cm^2/s	0.16 cm^2/s
Viscosity (20C, 100kPa)	8.814 µPa-s	11.023 µPa-s
Flame temperature (in air)	2045°C	
Minimum ignition energy (in air)	0.017 mJ	0.274 mJ

Propensity to Leak

The low viscosity and small molecular size of hydrogen gives it a greater propensity to leak than other common gaseous fuels. For the same pressure and hole size, hydrogen would leak approximately 2.8 times faster than natural gas and 5.1 times faster than propane on a volumetric basis. However, because the energy density of hydrogen is so much lower than that of methane or propane, the energy leakage rate for hydrogen would only be 0.88 times that of methane, and 0.61 times that of propane.

It is nearly impossible, unless you use all welded joints, to build a gaseous hydrogen plumbing system that is truly leak free. However, building a system that is as tight as possible and minimizes hydrogen gas leaks is obviously desirable. In addition, adequate ventilation in the vicinity of the hydrogen system is a must.

Dispersion

Hydrogen is more diffusive and more buoyant than gasoline, methane and propane, and therefore tends to disperse more rapidly. For low momentum gaseous hydrogen leaks, buoyancy affects gas motion more significantly than diffusivity. For high momentum leaks, which are more likely in high pressure systems, buoyancy effects are less significant, and the direction of the release will determine the gas motion. Localized air currents due to wind or ventilation will also affect gas movement. At low concentrations the effect of buoyancy becomes less significant because the density of the hydrogen-air mixture is similar to that of air.

As a consequence of these dispersion properties, hydrogen gas tends to disperse readily and form an ignitable mixture with air. However, in an unconfined atmosphere this

mixture will quickly dilute to levels below the lower flammability limit. So, although the rapid mixing properties of hydrogen lead to a more rapid formation of a combustible mixture, they also lead to a faster dispersal and generally shorter duration of a flammable hazard than for other fuels on an equal volume basis.

Hydrogen Gas and Flame Detection

Hydrogen is a colorless, odorless and tasteless gas. Its presence cannot be detected by human senses. In addition, the unique characteristics of a hydrogen fire make it difficult to perceive with the human senses. In contrast to other hydrocarbon fuels, which radiate most of their energy as visible light and heat, a hydrogen flame radiates significantly less heat and virtually no visible light. Instead, significant energy from a hydrogen flame is radiated in the ultraviolet region. As a result, hydrogen burns with a pale blue, almost invisible flame that is almost visually imperceptible in artificial light or daylight. Equally important, human physical perception of the heat from a hydrogen fire doesn't occur until direct contact with the combustion gases.

A broom has been used for locating small hydrogen fires. The idea is to hold the broom out in front of you while approaching the area where the hydrogen fire is suspected. A dry corn straw or sage grass broom will easily ignite when it comes in contact with the flame. A dry fire extinguisher or throwing dust into the air will also cause the flame to emit visible radiation.

Flammability and Ignition

Hydrogen has a much wider range of flammability in air (4% to 75% by volume) than methane (5% to 17% by volume), propane, or gasoline, and the minimum ignition energy (for a stoichiometric mixture) is about an order of magnitude lower ($1/16^{th}$ that of methane).

These characteristics would tend to indicate that flammability is a greater risk for hydrogen than for other fuels. However, these comparisons may not be as significant as they appear. In many accidental situations the lower flammable limit (LFL) is more important. The LFL for hydrogen is similar to that of methane, about twice that of propane and four times that of gasoline. In addition, the minimum ignition energy for hydrogen at the LFL is also similar to that of methane. Weak ignition sources, such as an electrostatic spark, are often noted as being sufficient to ignite a combustible hydrogen-air mixture. However, a weak electrostatic spark from the human body releases about 10 mJ, which is enough energy to ignite methane, propane, gasoline and other fuels as well.

Combustion Characteristics

Hydrogen-oxidizer mixtures can combust either as a fire at a fixed point, a deflagration, or a detonation. Depending on the rate of release of hydrogen from the source, fires can produce outputs ranging from that of a small candle to a high-pressure jet. At a fixed point hydrogen gas can burn as a jet flame, with combustion taking place along the edges of the jet where it mixes with sufficient air. In a stationary mixture in the open with no confinement a flammable hydrogen mixture will undergo slow deflagration. Deflagration refers to a flame that relies on heat- and mass-transfer mechanisms to combust and move into areas of unburnt fuel.

If the flame speed is accelerated, perhaps due to extreme initial turbulence or turbulence induced by obstacles or confinement, the result is an explosion. In the extreme case the flame speed becomes supersonic and results in detonation. Once initiated, detonation is self-sustaining (no further turbulence or confinement is required) as long as the combusting mixture is within the detonatable range. A detonation explosion is capable of causing much greater physical damage due to the significantly higher pressure that is generated (as great as 20 times the initial stoichiometric pressure versus about 8 times the initial pressure for a deflagration).

The lower radiation from a hydrogen flame makes the flame itself hotter than a hydrocarbon flame, and objects engulfed by a hydrogen flame tend to heat faster. However, the lower radiation of heat from the flame means that there is less heat transferred to objects or people outside the flame.

The heat of combustion of hydrogen per unit weight is higher than any other material, but hydrogen has a relatively low heat of combustion per unit volume. Thus the combustion of a given volume of hydrogen will release less energy than the same volume of either natural gas or gasoline.

Hydrogen Embrittlement and Material Compatibility

Prolonged exposure of some high strength steels to hydrogen can cause them to lose their strength, eventually leading to failure. This is known as hydrogen embrittlement and occurs when hydrogen permeates into the lattice structure of the material. Sensitivity to hydrogen embrittlement is influenced by numerous parameters, including plastic deformation, cyclic loading, hydrogen purity, temperature, and pressure. Hydrogen embrittlement is a particular issue for ferritic steels, and occurs at ambient temperatures and elevated pressures. The problem is exacerbated when the steel is subjected to mechanical stresses. The processes take place on freshly generated metallic surfaces that are likely to form at surface defects or other stress raisers as a result of stress-induced local plastic deformation processes.

Suitable metals for gaseous hydrogen service include austenitic stainless steel with greater than 7% nickel (such as 304, 304L, 308, 316, 321, 347), copper and its alloys (such as brass, bronze and copper-nickel), and aluminum and its alloys. Non-metallic materials that can be used in gaseous hydrogen service for valve seats, gaskets, etc. include Buna-N®, Viton®, Kel-F®, and Teflon®.

Physiological Hazards

Hydrogen is non-toxic, but it can cause asphyxiation in a confined area due to displacement of oxygen. Smoke inhalation, a primary cause of injury due to fires, is considered less serious in the case of hydrogen because the sole product of combustion is water. However, secondary fires can cause smoke and other combustion products that present a health hazard.

2. Handling Compressed Gases

The following information has been adapted from the Compressed Gas Association's pamphlet P-1, *Safe Handling of Compressed Gases in Containers* (2000) and Lawrence

Livermore National Laboratory's *Environmental Safety and Health Manual, Part 18.1: Pressure* (updated 2001).

Note: Only authorized, trained personnel should work with compressed gases.

- Use a four-wheel cylinder cart for moving gas cylinders. These cylinders are difficult to move manually because of their shape, smooth surface, and weight.
- Make sure that the protective valve cover is in place when a cylinder is not connected to a regulator or manifold.
- Mark partially filled cylinders with the remaining product pressure.
- Always assume a cylinder is pressurized; handle it carefully and avoid bumping or dropping. Never drop cylinders from trucks or any raised surface to the ground.
- Lifting a cylinder requires two people. Never lift a cylinder by the cylinder cap.
- Secure cylinders in suitable cradles or skid boxes before raising them with cranes, fork trucks, or hoists. Do not use ropes or chain slings alone for this purpose.
- Never use a gas cylinder as a roller for moving materials or for supporting other items.

Storage

General Practices. Cylinders are sometimes shipped tied horizontally on wooden pallets, individually contained by saddle blocks, and double-banded to prevent rolling and sliding. These are *not* recommended methods for cylinder storage. Use the following guidelines for cylinder storage:

- Store adequately secured cylinders upright on solid, dry, level footings, preferably outside of occupied buildings and away from traffic lanes.
- Shade cylinders stored in the sun during the summer, whenever possible.
- Store cylinders away from sources of intense heat (furnaces, steam lines, radiators).
- Do not stockpile gas beyond the amount required for immediate use.
- Ensure that containers stored or used in public areas are protected against tampering and damage. Furthermore, containers stored inside or outside should not obstruct exit routes or other areas that are normally used or intended for the safe exit of people.
- Always store cylinders with the protective caps in place.

Posting and Hazard Identification. The hazard classification and/or the name of the gases being stored should be prominently marked in container storage areas, and "NO SMOKING" signs should be posted where appropriate. Material safety data sheets (MSDSs) for the product(s) should be readily available and should be consulted for information on the specific hazards, safety precautions, and related emergency response procedures.

Gas storage cylinders should be marked to identify the gas contents and fill pressure. Properly label cylinders with stencils, DOT shoulder labels, cautionary side-wall labels,

or tags to identify the contents. Do not remove these labels without specific authorization from your appropriate safety officer. Color codes are not used to identify contents.

Adequately Secured. All compressed gas cylinders in service or storage should be secured to prevent them from falling. Cylinder and manifold racks should be equipped with two chains whenever possible. If available, both chains should be used to secure the cylinders.

Compatibility. Cylinders should be separated by compatibility of contents. For example, oxidizers should be kept separate from combustibles or flammables by a minimum distance of 20 ft or by a non-combustible barrier that is at least 5 ft high with a fire resistance rating of at least one-half hour.

Inspection

- Inspect hoses and manifolds frequently, and replace worn hoses and connections.
- Report leaking cylinders that contain hazardous materials to the appropriate safety officer. Evacuate the area until the emergency response team arrives.
- Contact your appropriate safety officer before handling faulty or corroded cylinders; these cylinders should be segregated. CAUTION: Only the vendor should alter or repair cylinders or cylinder valves.

General Precautions

- Secure both ends of gas hoses with a hose restraint to prevent whipping in the event the hose or fitting fails. For systems in occupied areas, support and secure the hose and tubing at least every 7 ft.
- Do not use an open flame to leak-check a gas cylinder; use soapsuds or a leak detection solution.
- Remove the talc and dust from a new hose before connecting it.
- Do not use white lead, oil, grease, or any other non-approved joint compound to seal the fittings on an oxygen system; a fire or an explosion could occur if oxygen contacts such materials. Threaded connections in oxygen piping should be sealed with solder, glycerin, or other sealants approved for oxygen service. Gaskets should be made of noncombustible materials.
- Never interchange regulators and hose lines with one type of gas for another. Explosions can occur if flammable gases or organic materials come in contact with oxidizers (e.g., oxygen) under pressure.
- Never use oxygen to purge lines, operate pneumatic tools, or dust clothing. Remember, oxygen is *not* a substitute for compressed air.
- Do not use vendor-owned cylinders for purposes other than as a source of gas. These cylinders may only be pressurized by the owner.
- Do not strike a welding arc on a cylinder.

- Before using equipment (regulators, pressure gauges, gas hoses, etc.) in a pressurized gas system, make sure that the equipment is adequately rated to meet system pressure requirements.

Operation

- After installing the regulator and before opening the cylinder valve, fully release (turning counterclockwise) the regulator pressure-adjusting screw.
- Open the cylinder valve slowly. Never use a wrench on a cylinder valve that will not rotate manually. Stand clear of pressure gauge faces when opening a cylinder valve.
- Keep removable keys or handles in place on valve spindles or stems while the cylinders are in service.
- Never leave pressure on a hose or line that is not being used. To shut down a system, close the cylinder valve and vent the pressure from the entire system.

Empty Cylinders

- Leave some positive pressure (a minimum of 20 psig) in empty cylinders to prevent "suck-back" and contamination.
- Close the valves on empty cylinders to prevent internal contamination; remove the regulators and replace the protective cap.
- Use a cylinder status tag to indicate whether the cylinder is "FULL," "IN SERVICE," or "EMPTY" or has "RESIDUE."
- Store empty cylinders separately from full cylinders.
- Call appropriate personnel to pick up cylinders that are no longer needed.

C. Safety Equipment and Guidelines

The following instructions and guidelines will help system operators to use the facility's safety equipment effectively.

1. Fire extinguishers

Fire extinguishers are located in the fuel cell test station area. See Section C.2 in this chapter for guidelines on controlling hydrogen fires and other types of fires. Fire extinguishers need to be clearly labeled according to the class of fire they are suitable for. These codes, as given in NFPA 10, are:

- Class A — Fires in ordinary combustible materials such as wood, cloth, paper, rubber, and many plastics.
- Class B — Fires in flammable liquids, oils, greases, tars, oil-base paints, lacquers and flammable gases.
- Class C — Fires that involve energized electrical equipment where the electrical conductivity of the extinguishing medium is of importance; when electrical equipment is de-energized, extinguishers for class A or B fires may be safely used.

- Class D — Fires of combustible metals such as magnesium, titanium, zirconium, sodium, lithium and potassium.

Fire extinguishers must be kept in their designated locations and in plain sight. Operators should notify the appropriate safety officer of any discharged, partially discharged, missing or mislocated fire extinguishers.

Fire extinguishers at the site should be of type A:B:C. Only Halon fire extinguishers should be used on a fire involving personal clothing. The materials from other extinguisher types can cause asphyxiation by cutting off oxygen to a person surrounded by the cloud of chemicals.

In order to effectively operate a fire extinguisher, one should remember P-A-S-S.

P -- Pull the pin

A -- Aim the hose at the base of the fire

S -- Squeeze the handle

S -- Sweep the hose back and forth

2. Hydrogen Gas Detection

A portable hydrogen gas or combustible gas detector can be used to check for hydrogen leaks at the fuel cell test station. Such a device can be a useful diagnostic tool when trying to locate a leak in the hydrogen system plumbing.

3. Hydrogen Flame Detection

The unique characteristics of a hydrogen fire make it difficult to perceive with the human senses. The flame is nearly invisible, especially in daylight, and perception of the heat from a hydrogen fire doesn't occur until direct contact with the combustion gases. A dry corn straw or sage grass broom can be used to detect small hydrogen fires by holding the broom out in front of you while approaching the area where the hydrogen fire is suspected. Alternatively, a portable UV detector can be used to detect hydrogen fires.

4. Safety Glasses

Operators should wear safety glasses whenever working in the fuel cell test station lab or performing any operations involving the hydrogen plumbing or hazardous substances. In order to ensure proper eye protection is used, eyewear should be comfortable, fit snugly over the eyes and around the face, and not impede the wearer’s movement. To maintain optimal safety, eye protection should be maintained in good condition and be capable of being cleaned and/or disinfected.

5. Hearing Protection

When performing tasks with high pressure gases such as changing out cylinders, testing pressure relief devices, etc. it is a good idea to wear hearing protection. If a fitting or

component in the high pressure gas system were to rupture there would be a loud noise capable of causing hearing damage.

6. Fire Blanket

The fuel cell test station area should be equipped with a fire blanket. This can be used to extinguish a fire involving somebody's clothing or hair. The appropriate procedure for extinguishing such a fire is to have the victim stop, drop and roll on the floor with the blanket wrapped around their body.

D. Hazard Identification and Response

The primary potential hazards associated with the test station include:

- high-pressure gas accidents,
- fire, and
- electric shock.

This section of the O&M Manual discusses these hazards and the appropriate response to hazardous incidents.

1. High Pressure Hazards

Any gas can be dangerous to handle at high pressure, flammable or not. Hazards associated with gas leaks in the high-pressure hydrogen system include: injury from projectiles associated with a catastrophic failure of high pressure plumbing, fire and explosion hazards, asphyxiation via oxygen displacement, hose whipping, gas entrainment in the blood system due to direct contact of a high pressure gas stream with the skin, and hearing damage due to a loud noise associated with a high pressure gas system rupture.

Hydrogen for the fuel cell test station is stored in compressed gas cylinders at about 2000 psig (when full). The cylinder regulator reduces the hydrogen gas pressure to about 100 psig immediately as it leaves the high pressure cylinder. The pressure is further reduced to a low level of only 3 to 5 psig before the hydrogen gas reaches the fuel cell.

! **Note:** Only authorized, trained personnel should work with compressed gases.

RESPONSE:

A hydrogen gas leak or high pressure rupture has the potential for fire and/or explosion. Rapid response is the best way to prevent or minimize equipment damage and personnel injury. If a hydrogen gas system leak or rupture occurs, perform the following steps:

a. Shut down the fuel cell test station by pushing the emergency shutdown button on the front panel of the safety tray in the electronics cabinet or by tripping the circuit breaker that provides test station power at the main electrical panel

(whichever is safer). An emergency shutdown will close all solenoid valves and shut off power to all components except the control computer and the electronic load. (Note: Electrical power to the control computer and the electronic load cannot be easily shut off because it is supplied via the UPS). This will slow and eventually stop the leak unless the gas is coming from upstream of the solenoid valve. If the leak is from upstream of the solenoid valve and it is safe to do so, close the cylinder valve to stop the gas flow.

b. Isolate the area to prevent personnel injury.

c. If the gas leak has been stopped and adjacent equipment or structures have caught on fire, put out the fire using an extinguisher or call the fire department.

d. Post warning signs and isolate the area until the high pressure or gas leak hazard has been resolved.

2. Fire and Combustion Hazards

Hydrogen gas constitutes the single greatest fire hazard on the fuel cell test station. See Section A.2 of this chapter for a description of the basic properties of hydrogen gas. Hydrogen gas under pressure, as in this system, can be a special fire hazard because pressurization allows the storage of large quantities of fuel in a relatively small space.

RESPONSE:

Hydrogen fires are nearly invisible, especially during daylight hours. If you have any suspicion that a hydrogen fire may be burning in a particular area, it is best to stay away from that area. If you must enter the area, do so cautiously and slowly with an infrared detector to check your path in front of you. Do not proceed if the infrared detector shows a significant heat source in your path. If an infrared detector is not available, hold a broom extended in front of you. If the broom scorches or catches fire, do not proceed.

Guidelines for Extinguishing Hydrogen Fires

The only safe way to extinguish a flammable gas fire is to stop the flow of gas. If the flow cannot be stopped, allow the entire contents of the cylinder to burn. Cool the cylinder and surroundings with water from a suitable distance. Extinguishing the fire without stopping the flow of gas may permit the formation of ignitable or explosive mixtures with air. These may propagate to a source of ignition.

Excessive pressure may develop in gas cylinders exposed to fire. This can result in explosion regardless of cylinder contents (initial pressure or gas type). Cylinders with pressure relief devices (PRDs) may release their contents through such devices when exposed to fire. Cylinders without PRDs have no provision for controlled release and are therefore more likely to explode if exposed to fire.

Small Fires: Use one of the fire extinguishers located in the fuel cell test station area.

Large Fires: Evacuate the premises and contact the fire department immediately (dial 911).

- Stop the flow of gas if at all possible. This is the top priority. To do this, shut down the fuel cell test station by pushing the emergency shutdown button on the front panel

of the safety tray in the electronics cabinet or by tripping the circuit breaker that provides test station power at the main electrical panel (whichever is safer). An emergency shutdown will close all solenoid valves and shutoff power to all components except the control computer and the electronic load. This will slow and eventually stop the leak unless the gas is coming from upstream of the solenoid valve. If the leak is from upstream of the solenoid valve and it is safe to do so, close the cylinder valve to stop the gas flow.

- Shut off all electrical power to the test station, UPS, and surrounding areas by tripping the circuit breakers in the main electrical panel. (Note: Electrical power to the control computer and the electronic load cannot be easily shut off because it is supplied via the UPS).
- Approach the fire from an upwind position, as the flame can flash downwind very easily.
- Extinguish the fire by aiming the fire extinguisher hose at the base of the fire, squeezing the handle and sweeping the hose back and forth.
- If necessary, allow the fire to burn itself out. This should happen quickly if the flow of hydrogen is stopped, as hydrogen disperses rapidly.
- Provided all electrical power in the area has been disconnected, spray flammable materials near the fire with a water mist or soak the materials in some other manner to prevent the fire from spreading.
- It is especially critical to spray the hydrogen cylinder with water if they are exposed to flame or extreme heat. This will prevent the cylinders from rupturing. If insufficient water is available to keep the cylinders cool, evacuation of the area is recommended.
- If there is a chance that pure oxygen or compressed air is mixing with the burning hydrogen, the flow of oxygen or compressed air should be shut off immediately.
- Post warning signs and isolate the area until the fire and combustion hazard has been resolved.

3. Electric Shock Hazards

The fuel cell test station uses 120 VAC single-phase power, as well as 5 VDC, ±15 VDC, and 24 VDC power for system operation and control. In addition, the test station is equipped to handle DC power output from a fuel cell ranging from 0 to 200 Amps DC and 0 to 30 VDC. The 120 VAC power can produce a shock resulting in injury or death. It is imperative that system operators follow standard electrical safety procedures when working with these components (see the lockout/tagout procedure below).

Remember that circuits on the test station may be energized even when the system is in standby mode. In addition, even when power to circuits has been disconnected, stored electrical energy (i.e. in capacitors or batteries) may maintain high voltages on particular electrical components. Before performing maintenance on or near any electrical components, the technician should check for high voltages on electrical circuits using a voltmeter.

Water and electricity are both present on the fuel cell test station. Together, water and electricity can be a deadly combination. System operators must use special caution when

working at the test station if water or other liquids have been spilled or have leaked in the vicinity of the test station.

Note: Only authorized, trained personnel should work with the fuel cell test station electrical system.

RESPONSE:

If a person receives an electric shock, take the following steps:

1. Do not touch the victim if there is any possibility that they are still in contact with a live electrical circuit.
2. If necessary, use a plastic or wooden implement such as a broomstick (something that is NOT electrically conductive) to push the victim away from the live electrical circuit.
3. Once the victim is safely separated from the electrical circuit, check for breathing and a pulse. If the victim is not breathing, administer rescue breathing. If the victim does not have a pulse administer cardiopulmonary resuscitation (CPR).
4. Call 911.
5. Keep the victim warm.
6. The victim should not eat or drink until he or she has been seen by a doctor.
7. If an electrical shock hazard is still present at the test station, shut off electrical power to the test station by tripping the circuit breaker that provides test station power at the main electrical panel. This will shut off power to all components on the test station except the control computer and the electronic load. These components are supplied power via the UPS, and this power cannot be easily disconnected.
8. Post warning signs and isolate the area until the electrical hazard has been resolved.

E. Safety Policies

System operators must adhere to the following safety policies when operating the fuel cell test station:

- Only trained, authorized personnel should be allowed to operate and maintain the fuel cell test station.
- Personnel working with high pressure gases, flammable gases and/or electrical systems must have adequate training and experience.
- Use appropriate personal safety equipment on the job. Wear safety glasses at all times when working in the fuel cell test station area or working with high pressure gases. Wear hearing protection when working with high pressure gases.
- Use the “buddy system” (work with at least one other researcher present and ready to assist in case of an accident or emergency) when performing any operation, maintenance or troubleshooting tasks on the fuel cell test station. Never perform system operation, maintenance or repair tasks alone.
- Be familiar with facility-wide safety policies.

Tagout/Lockout Procedure

When any component on the fuel cell test station is being serviced or repaired, operators must use the following tagout or lockout procedures to ensure personnel safety and avoid accidental restarting of equipment during service procedures. The purpose of a tagout is to provide clear notification to all personnel that the system or a system component is being serviced and must not be operated. A lockout's purpose is to physically prevent operators (or anyone else) from starting the system or system component while it is being serviced. Devices used for tagout/lockout must meet requirements found in 29 CFR 1910.147, The Control of Hazardous Energy (Lockout/Tagout), and 29 CFR 1910.333, Selection and Use of Work Practices (Electrical Safety-Related Work Practices). If a piece of equipment is tagged out but not locked out, one additional safety anti-start measure must be employed, such as opening of a circuit disconnect or physical blocking of mechanical equipment. All new or temporary operators or operator's assistants must be shown these lockout/tagout procedures before working with the fuel cell test station.

- Notify *all* personnel who operate or work in the vicinity of the equipment that a tagout or lockout is being implemented, and which piece or pieces of equipment will be affected.
- Make sure that the person performing the tagout or lockout is familiar with the equipment being serviced and knows how to tagout or lockout the equipment properly and safely.
- If the equipment to be serviced is in use, shut down the fuel cell test station.
- Isolate any electrical equipment to be serviced from the electrical system by disconnecting its source of power. Make sure that no residual energy (e.g. capacitors) presents a safety threat.
- Depressurize the hydrogen gas system if any gas system equipment is to be serviced.
- Tagout or lockout the opened electrical disconnects, electrical power plugs or closed gas system valves that have been used to isolate the equipment being serviced.
- Check that no personnel are working on or near the equipment to be serviced, then test that the electrical disconnect tagout/lockout is in effect by trying to start the equipment. If the equipment starts, it has not been isolated correctly. If the equipment does not start, proceed with servicing.
- When servicing is completed, make sure all personnel are clear of the equipment, remove tagout/lockout devices, close the electrical disconnect(s), and re-start equipment as appropriate.

F. Material Safety Data Sheets (MSDS)

A Material Safety Data Sheet (MSDS) for hydrogen is included in Appendix D of this manual. MSDSs provide safety information on any potentially hazardous or toxic substances. An MSDS is required to provide the following information:

- Product and company information
- Composition/ingredient information

- Hazards identification
- First aid measures
- Fire fighting measures
- Accidental release measures
- Handling and storage
- Exposure controls
- Personal protective equipment
- Physical/chemical properties
- Stability and reactivity
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information

G. Additional Informational Resources

SERC recommends that test station users consult the following documents for more detailed information on working safely with hydrogen.

National Aeronautics and Space Administration, *Safety Standards for Hydrogen and Hydrogen Systems.*

International Standards Organization. *Basic Considerations for the Safety of Hydrogen Systems*. ISO/PDTR 15916. 2002.

Cracknell , R.F. et al. Safety Considerations in Retailing Hydrogen. Presented at the 14th World Hydrogen Energy Conference. Montreal. June 9-13, 2002.

Hansel, J.G. et al. Safety Considerations in the Design of Hydrogen Powered Vehicles. *International Journal of Hydrogen Energy.* Vol. 18, No. 9, pp 783-790. 1993.

Air Products Corporation, Safetygram-4, *Gaseous Hydrogen*.

U.S. Department of Energy *Pressure Safety Manual* Final Draft, December 1993.

Compressed Gas Association Documents:

CGA High Pressure Gas Video

CGA-G5, *Hydrogen*

CGA G-5.4, *Standard for Hydrogen Piping Systems at Consumer Locations*

CGA S-1.3, *Pressure Relief Device Standards - Part 3 - Stationary Storage Containers for Compressed Gases*

CGA G-5.5, *Hydrogen Vent Systems*

CGA P-1, *Safe Handling of Compressed Gases in Containers*

National Fire Protection Association, NFPA 50A Standard for Gaseous Hydrogen Systems at Consumer Sites.

Appendix A: System Specifications and Drawings

SCHATZ ENERGY RESEARCH CENTER

Specifications
Fuel Cell Test Station

Stack Specifications	
Maximum number of cells	32
Power rating	4 kW
Maximum current	180 Amps
Fuel System	
Pressure regulation (manual pressure regulator)	0 - 10 psig
Automatic/manual fuel gas purge	Programmable time interval
Air System	
Air mass flow controlled with range switching	0 - 200 slm (± 1.0 slm)
Less than 2 sec. Wake-up response	
Stoichiometrically load following	
Blower controlled	0-200 slm
Stoichiometry software controlled	0 - 600%
DI Water Cooling System	
Heater	400 watts
Cooling fan/heat exchanger	4 slm water flow, 2.5 kW heat removal
Automatically/manually filled DI reservoir	
Software controlled stack temperature	
Manually controlled water flow	
Computer Control	
Signal conditioning	5B backplane hardware
Data acquisition	PCI DAQ boards
Software	LabVIEW 6i
Platform/Operating System	Computer Specs as Desired
Data logging	Automated[1]
Electronic Load	
4 kW DynaLoad with GPIB interface	software or manual control
Voltage limited	0 - 10 V, 0 - 50 V, 0 - 100 V (± 0.5%)
Current limited	0 - 20 A, 0 - 200 A, 0 - 600 A (± 0.5%)
Power limited	0 - 4 kW (± 3%)
Software based IV curve testing	
Data Monitoring[1]	
Automatic longterm data logging	programmable time interval
Individual cell voltages (30 channels)	0 - 1200 mV/cell (± 1 mV/cell)
Fuel cell current (with alternate ranges)	0 - 1000 A (± 0.03 A)
	0 - 500 A (± 0.015 A)
H_2 inlet pressure	0 - 30 psia (± 0.4 %)
H_2 inlet flow	0 - 100 slm (± 1.0 slm)
Air inlet pressure	0 - 5 psig, (± 0.25%)
Air inlet flow	0 - 100 slm (± 1.0 slm)
	0 - 500 slm (± 5.0 slm)
Water temperature in/out heat exchanger	0 - 100°C
Water temperature in/out fuel cell	0 - 100°C
Water flow meter	1-10 L/min (± 3%)
DI water conductivity	0 - 10 uS (± 2%)
Fuel cell operating temperature	0 - 100°C

Specifications (continued)

Software Safety Triggers, with alarms[2]	
Low cell voltage	programmable limit
Low/high H_2 inlet pressure	programmable limit
Low/high air inlet pressure	programmable limit
High stack temperature	programmable limit
High cooling water conductivity	programmable limit
H_2 system leak	programmable limit
Emergency shutdown	

Hardware Safety Triggers, with alarms[3]	
Uninterruptible power supply for entire station	
Station area H_2 Sensor	
Station area smoke detector	
Computer watchdog timer	hardware shutdown if computer freezes
Automatic emergency shutdown	
Manual emergency shutdown	
Hydrogen pressure relief device	>10 psig
Water reservoir overfill drain	
Station area vent fan	

Station Requirements	
Voltage	120 VAC
Frequency	60 Hz
Current	30 amps
DI water	< 5 µS,
Pressurized H_2	5 - 3000 psig
Compressed, oilless Air	20-100 psig
Water lines for exhaust (H_2 and Air)	
H_2 Vent/fan	

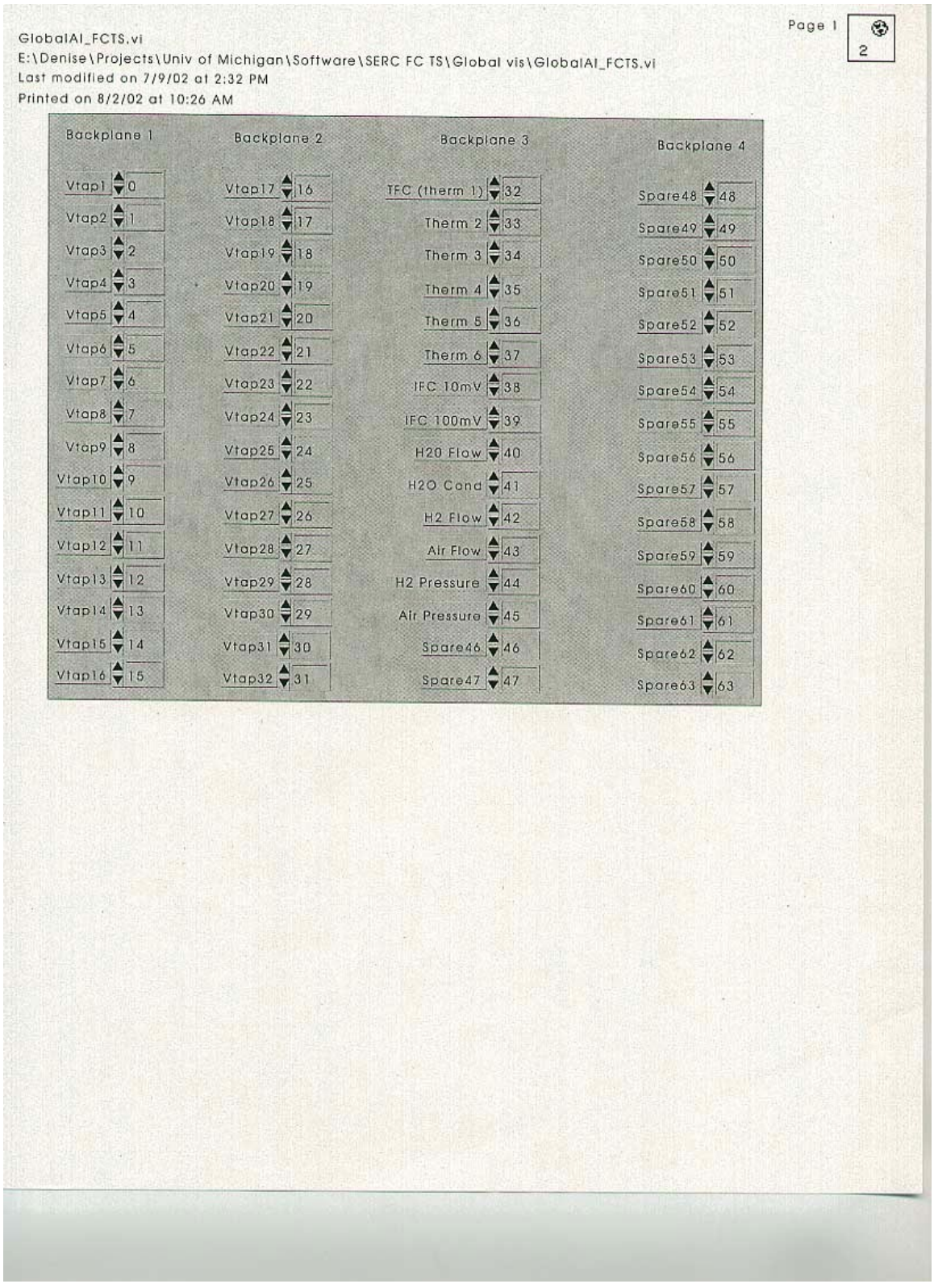
The software will produce a data file recording system data. The maximum time interval between successive records will be user selectable. In addition, the system will record data whenever selected channels change by more than a selectable amount. The system will automatically open new data files at midnight or other selected times. The user may include header lines in the file to record characteristics of the fuel cell being tested.

The software will automatically shut down the system whenever specific analog or digital inputs exceed user selectable limits. The reason for the shutdown will be displayed on the monitor. The state of the hardware safety circuit is one of the digital inputs to the software.

The hardware safety circuit is a software-independent unit that will automatically disconnect the electronic load, close the hydrogen and air supply valves, and sound an alarm.

University of Michigan IO List

Subsystem	*Channel*	*Type*	*Global Variable*	*Physical Range*	*Sensor Output*	*Excitation Voltage*	*Excitation Current*	*Hardware*
Electrical	0 thru 31	AI	VTap #	0-5V	0-5 V	NA	NA	Custom Wire Tap
Cooling	32	AI	TH20 out PS	0-200 deg C	NA	NA	NA	T Thermocouple
Cooling	33	AI	TH20 in FC	0-200 deg C	NA	NA	NA	T Thermocouple
Cooling	34	AI	TH20 out FC	0-200 deg C	NA	NA	NA	T Thermocouple
Cooling	35	AI	Therm 4	0-200 deg C	NA	NA	NA	T Thermocouple
Cooling	36	AI	Therm 5	0-200 deg C	NA	NA	NA	T Thermocouple
Cooling	37	AI	Therm 6	0-200 deg C	NA	NA	NA	T Thermocouple
Electrical	38	AI	IFC	0-40 Amps	0-10 mV	NA	NA	Current Shunt
Electrical	39	AI	IFC	0-200 Amps	0-50 mV	NA	NA	Current Shunt
Cooling	40	AI	QH20	1-10 L/min				Vol. Flow meter
Cooling	41	AI	H20 Cond	0-10 uS	4-20 mA	12-36 V	30 mA	Conductivity meter
Hydrogen	42	AI	QH2	0-100 slm	0-5 V	(+/-) 15 V	(+/-)50 mA	MFT
Air	43	AI	QAir	0-200 slm	0-5 V	(+/-) 15 V	200 mA	MFC
Hydrogen	44	AI	PH2	0-30 psig	1-5 V	10-30 V	3 mA	Press. Transducer
Air	45	AI	PAir	0-5 psig	0-5 V	13-30 V		Press. Transducer
Safety	46	AI	dP in room, safety	psig	unknown	unknown	unknown	dP Transducer
	47 thru 63	AI	Spare					
Air	0	AO	Qair MFC	0-200 slm	0-5 V	NA	NA	MFC
Air	1	AO	Qair Blower	0-200 slm	0-20 mA			Blower
	2 thru 3	AO	Spare					
Cooling	0	DI	Reservoir Float Switch	NA	NA	24 V		Float Switch
	1 thru 7	DI	Spare					
Safety	8	DO	Watchdog Timer	NA	NA	24 V		Watchdog Module
Electrical	9	DO	Load Contactor	NA	NA	24 V		Contactor
Hydrogen	10	DO	H2 Supply Solenoid	NA	NA	24 V	0.5 A	Solenoid Valve
Air	11	DO	Air Supply Solenoid	NA	NA	24 V	0.5 A	Solenoid Valve
Cooling	12	DO	Res Fill Solenoid	NA	NA	24 V	0.5 A	Solenoid Valve
Hydrogen	13	DO	H2 Purge Solenoid	NA	NA	24 V	0.9 A	Solenoid Valve
Cooling	14	DO	Reservoir Fans	NA	NA	24 V		4 Fans
Air	15	DO	Air Supply Solenoid	NA	NA	24 V	0.5 A	Solenoid Valve
Air	16	DO	Blower Power	NA	NA	24 V		Blower
Cooling	17	DO	AC Outlet 1 ~ Pump	NA	NA	120 VAC	1.0 A	Switched Outlet
Cooling	18	DO	AC Outlet 2 ~ Res Heaters	NA	NA	120 VAC	0.8 A	Switched Outlet
Cooling	19	DO	AC Outlet 3 ~ Res Heaters	NA	NA	120 VAC	0.8 A	Switched Outlet
Cooling	20	DO	AC Outlet 4 ~ Heat Tape	NA	NA	120 VAC	2.5 A	Switched Outlet
	21	DO	AC Outlet 5 ~ Spare	NA	NA	120 VAC		Switched Outlet
	22	DO	AC Outlet 6 ~ Spare	NA	NA	120 VAC		Switched Outlet
	23		AC Outlet 7 ~ Spare	NA	NA	121 VAC		Switched Outlet
	24		AC Outlet 8 ~ Spare	NA	NA	122 VAC		Switched Outlet
	25 thru 32	DIO	Spare					


Page 1
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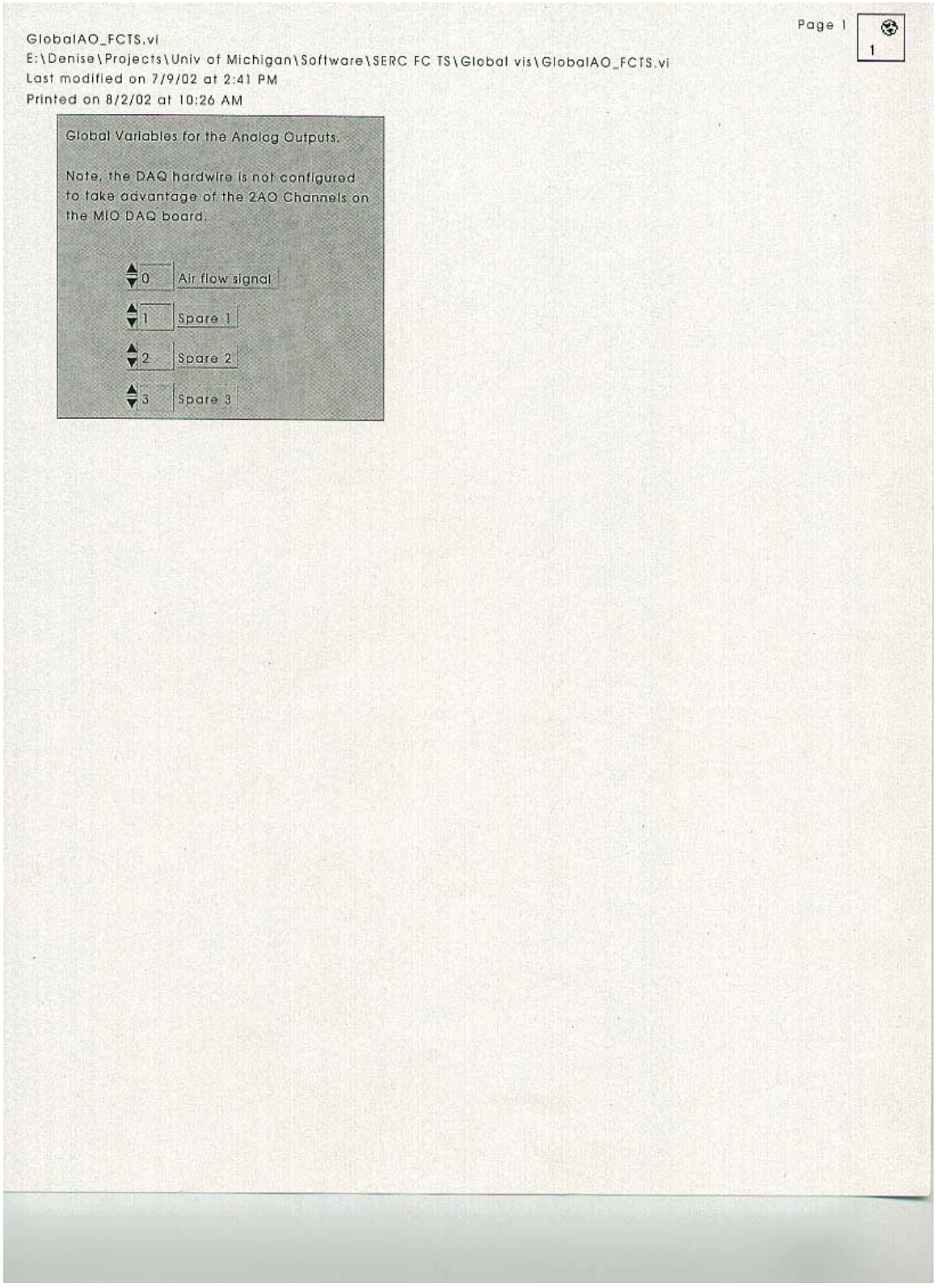
Printed on 8/2/02 at 10:26 AM
Backplane 1
Vtap1 0
Vtap2 1
Vtap3 2
Vtap4 3
Vtap5 4
Vtap6 5
Vtap7 6
Vtap8 7
Vtap9 8
Vtap10 9
Vtap11 10
Vtap12 11
Vtap13 12
Vtap14 13
Vtap15 14
Vtap16 15
Backplane 2
Vtap17 16
Vtap18 17
Vtap19 18
Vtap20 19
Vtap21 20
Vtap22 21
Vtap23 22
Vtap24 23
Vtap25 24
Vtap26 25
Vtap27 26
Vtap28 27
Vtap29 28
Vtap30 29
Vtap31 30
Vtap32 31
Backplane 3
TFC (therm 1) 32
Therm 2 33
Therm 3 34
Therm 4 35
Therm 5 36
Therm 6 37
IFC 10mV 38
IFC 100mV 39
H20 Flow 40
H2O Cond 41
H2 Flow 42
Air Flow 43
H2 Pressure 44
Air Pressure 45
Spare46 46
Spare47 47
Backplane 4
Spare48 48
Spare49 49
Spare50 50
Spare51 51
Spare52 52
Spare53 53
Spare54 54
Spare55 55
Spare56 56
Spare57 57
Spare58 58
Spare59 59
Spare60 60
Spare61 61
Spare62 62
Spare63 63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1
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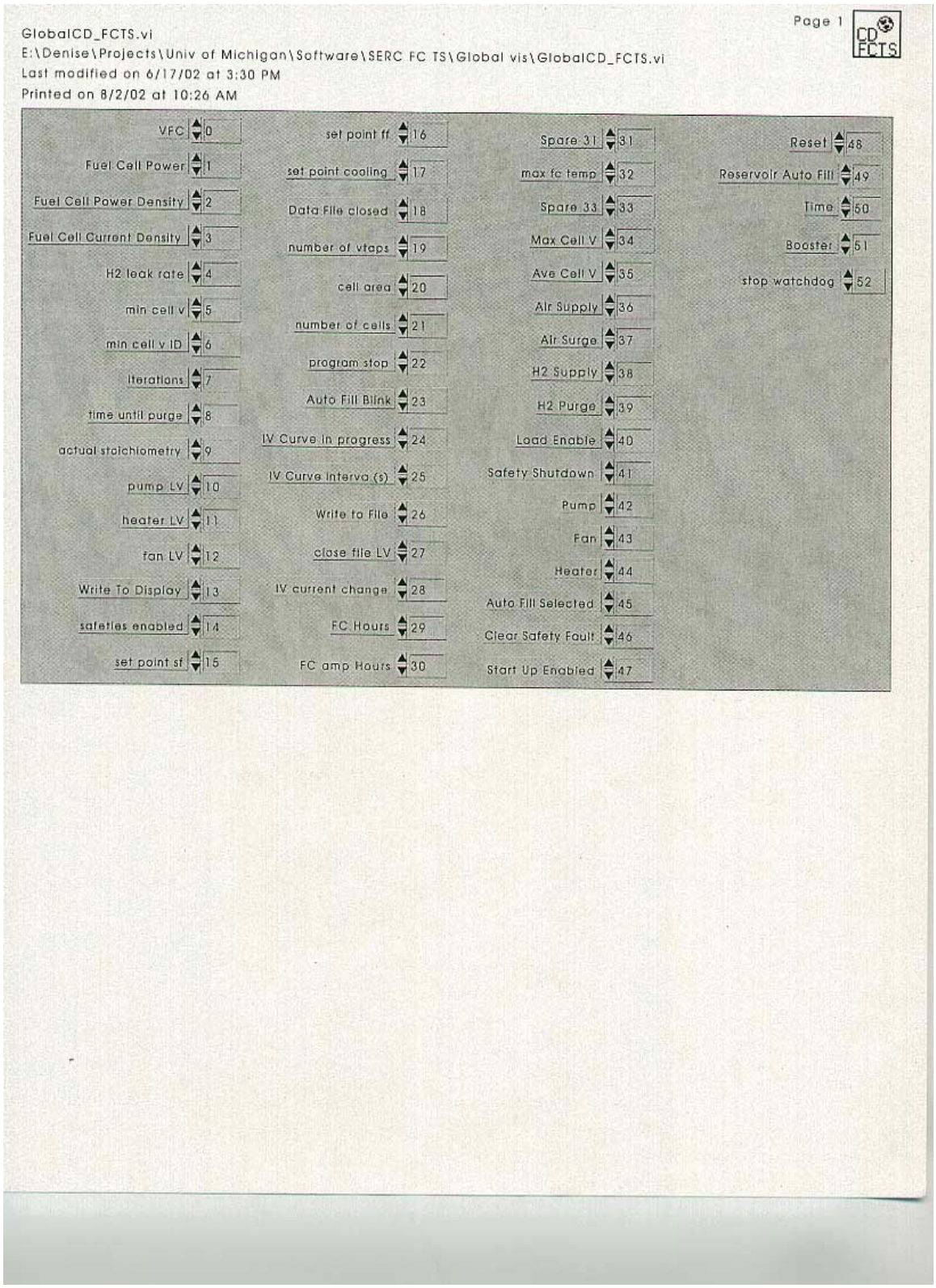
Last modified on 7/9/02 at 2:41 PM
Printed on 8/2/02 at 10:26 AM
Global Variables for the Analog Outputs.
Note, the DAQ hardwire is not configured to take advantage of the 2AO Channels on the MIO DAQ board.
0
Air flow signal
1
Spare 1
2
Spare 2
3
Spare 3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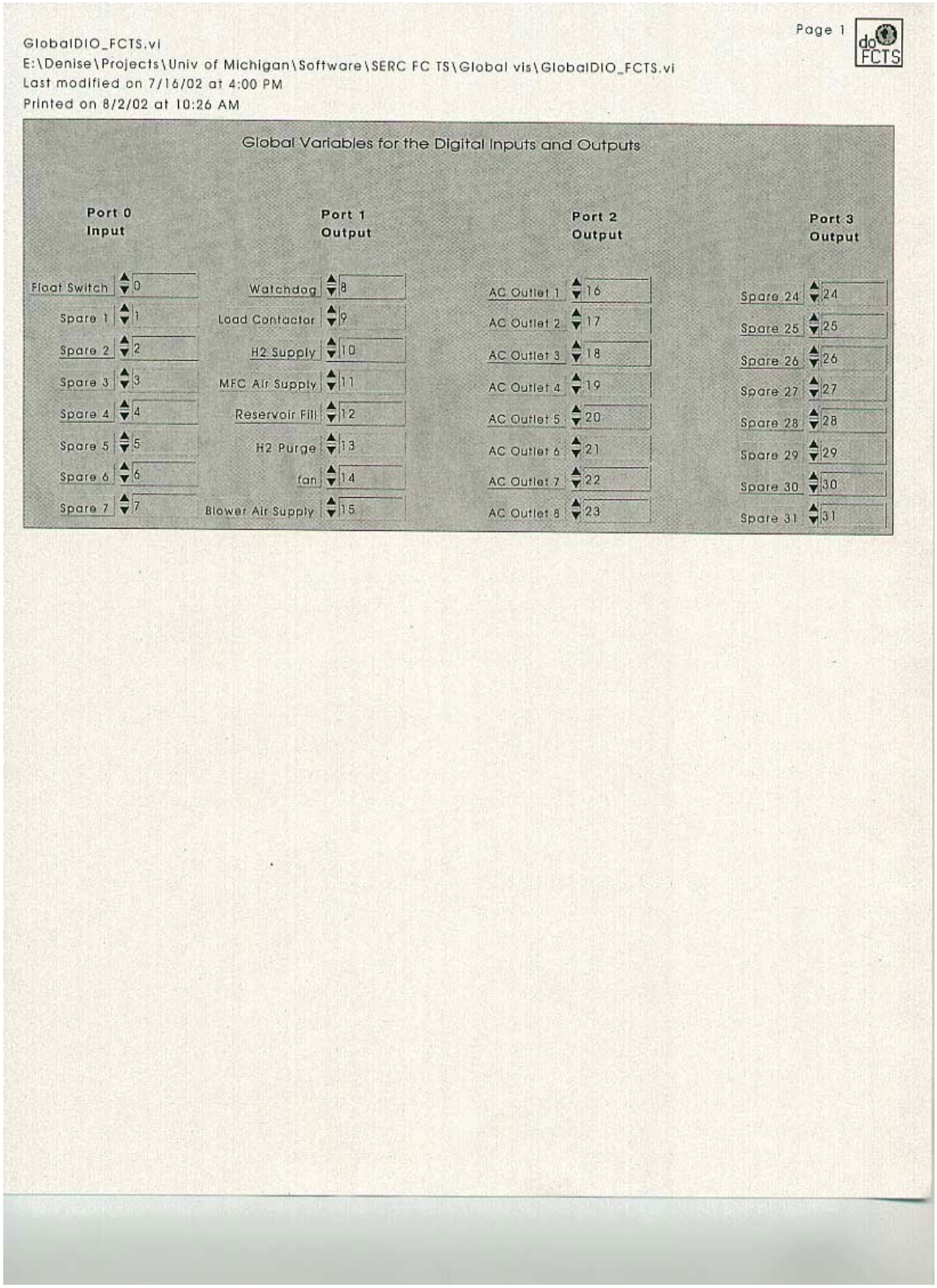
Last modified on 6/17/02 at 3:30 PM
Printed on 8/2/02 at 10:26 AM
Page 1
CD FCTS
VFC 0
Fuel Cell Power 1
Fuel Cell Power Density 2
Fuel Cell Current Density 3
H2 leak rate 4
min cell v 5
min cell v ID 6
Iterations 7
time until purge 8
actual stoichiometry 9
pump LV 10
heater LV 11
fan LV 12
Write To Display 13
safeties enabled 14
set point sf 15
set point ff 16
set point cooling 17
Data File closed 18
number of vtaps 19
cell area 20
number of cells 21
program stop 22
Auto Fill Blink 23
IV Curve in progress 24
IV Curve interva (s) 25
Write to File 26
close file LV 27
IV current change 28
FC Hours 29
FC amp Hours 30
Spare 31 31
max fc temp 32
Spare 33 33
Max Cell V 34
Ave Cell V 35
Air Supply 36
Air Surge 37
H2 Supply 38
H2 Purge 39
Load Enable 40
Safety Shutdown 41
Pump 42
Fan 43
Heater 44
Auto Fill Selected 45
Clear Safety Fault 46
Start Up Enabled 47
Reset 48
Reservoir Auto Fill 49
Time 50
Booster 51
stop watchdog 52


Page 1
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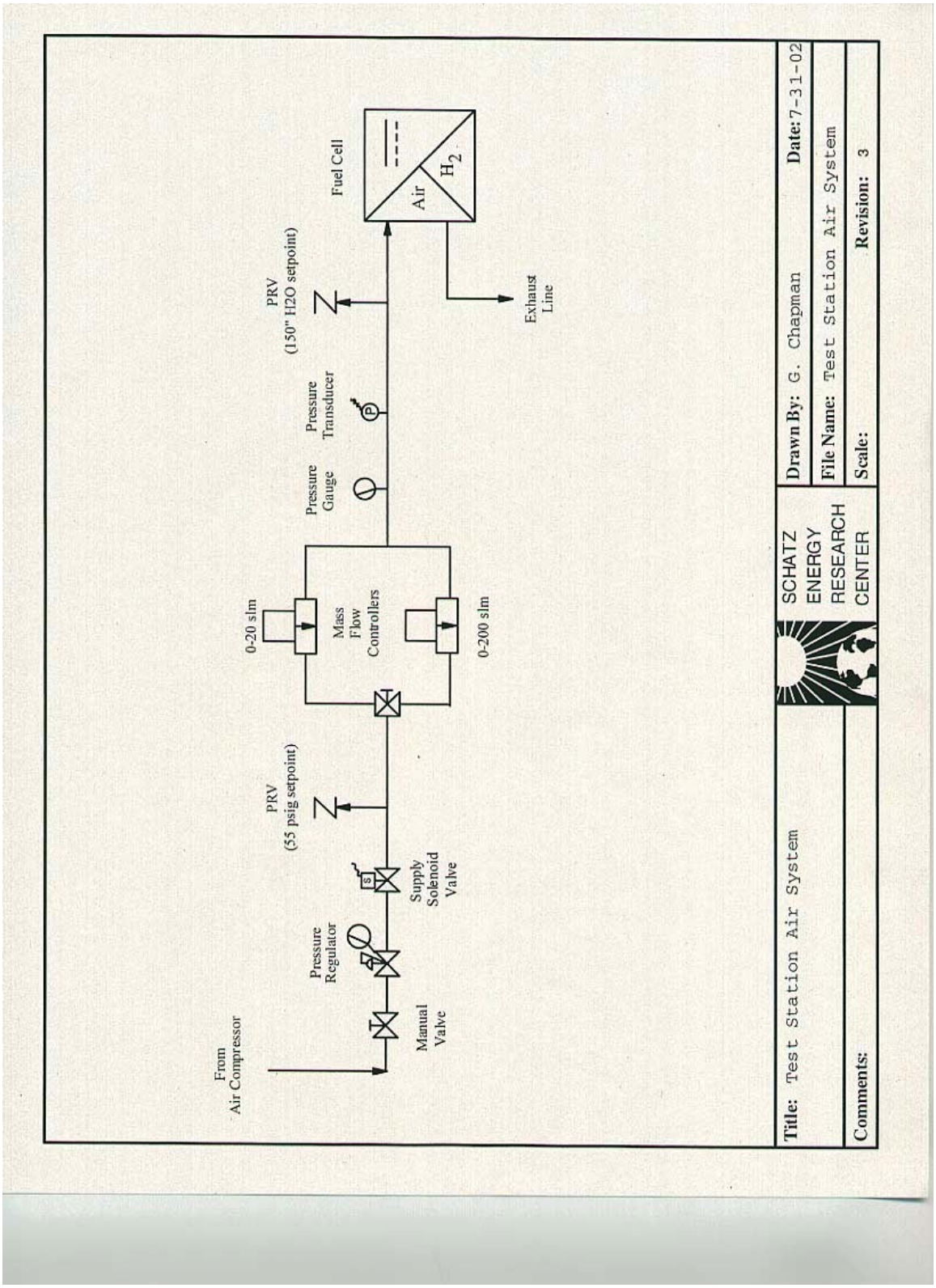
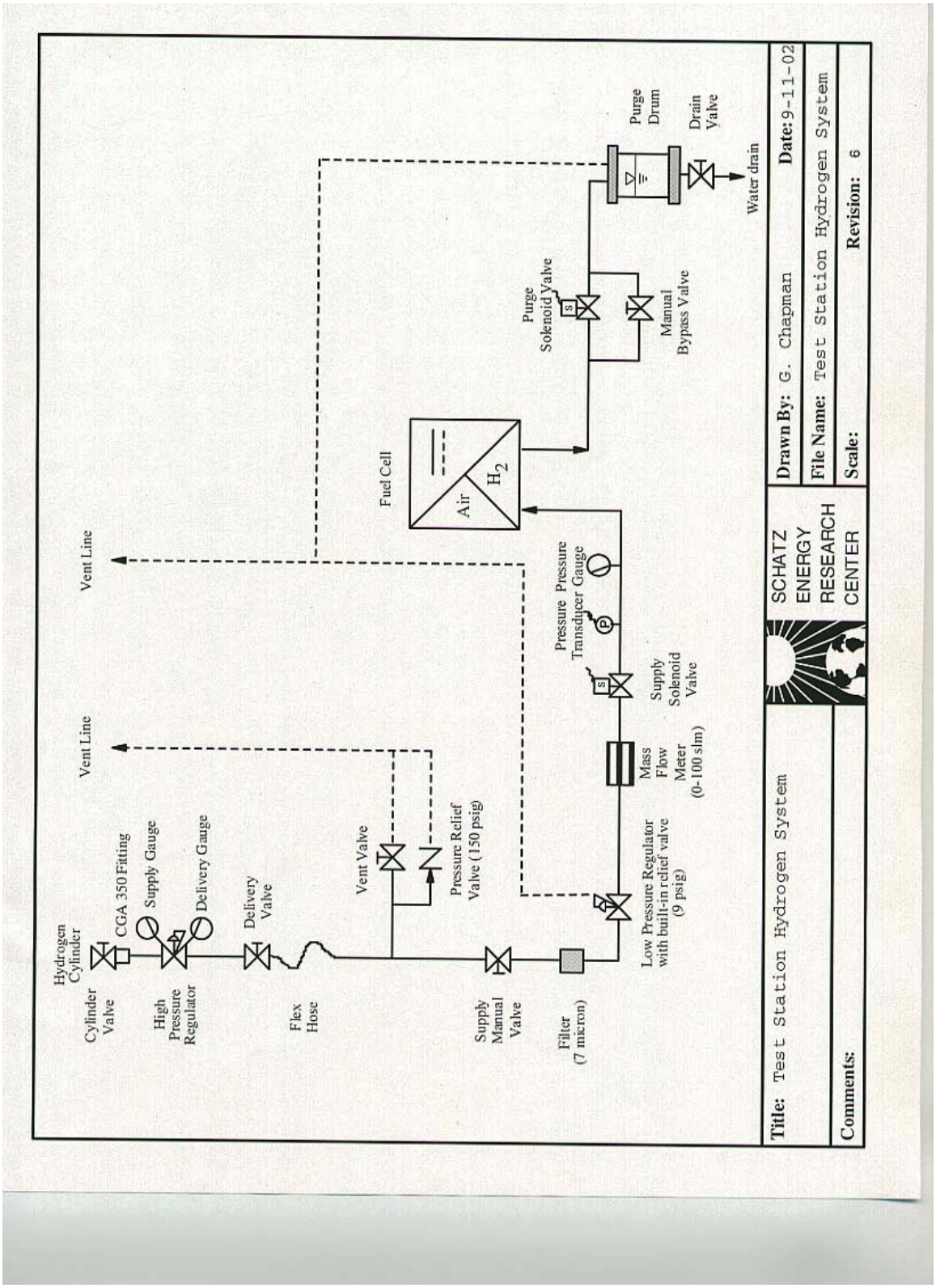
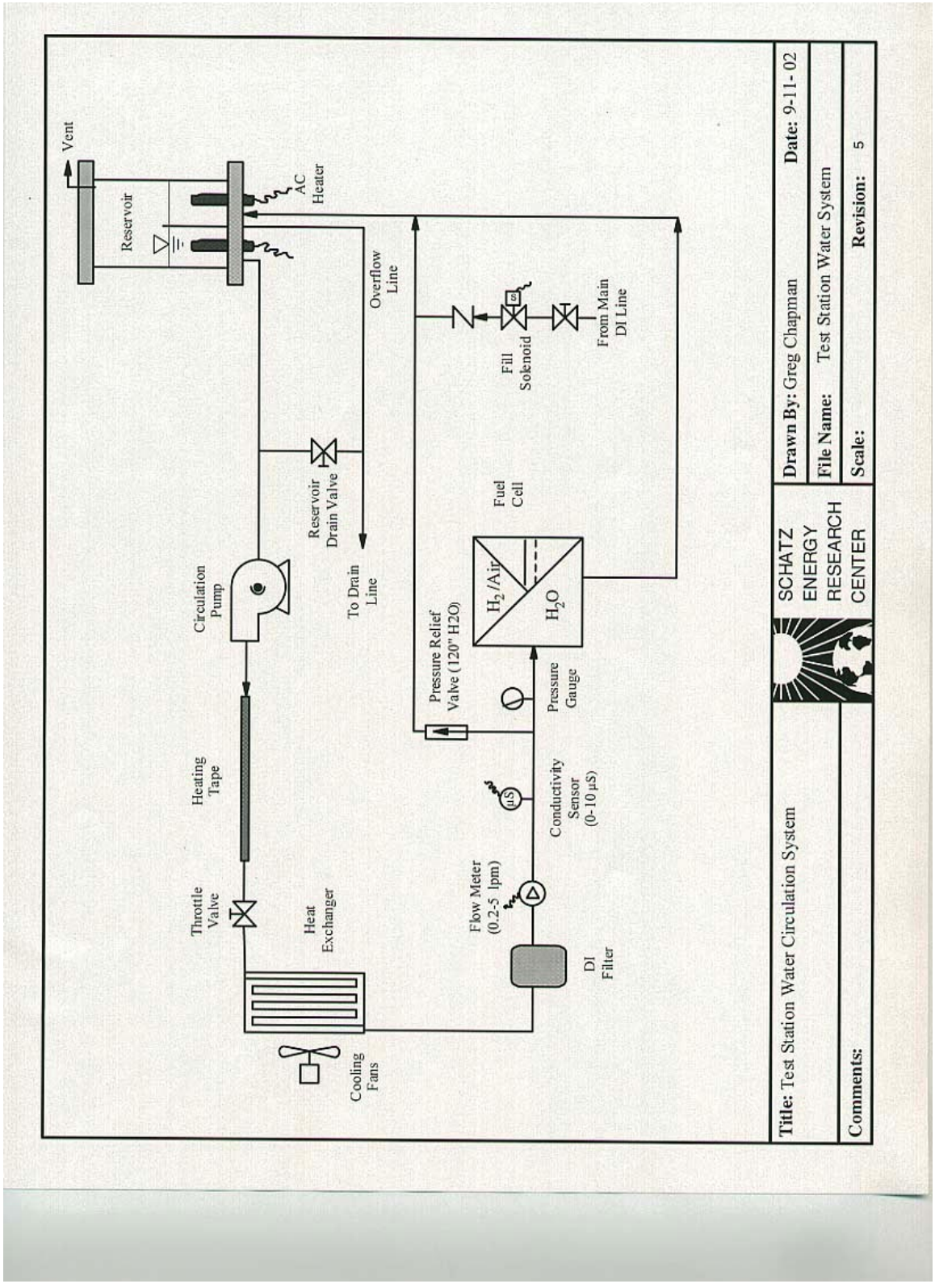
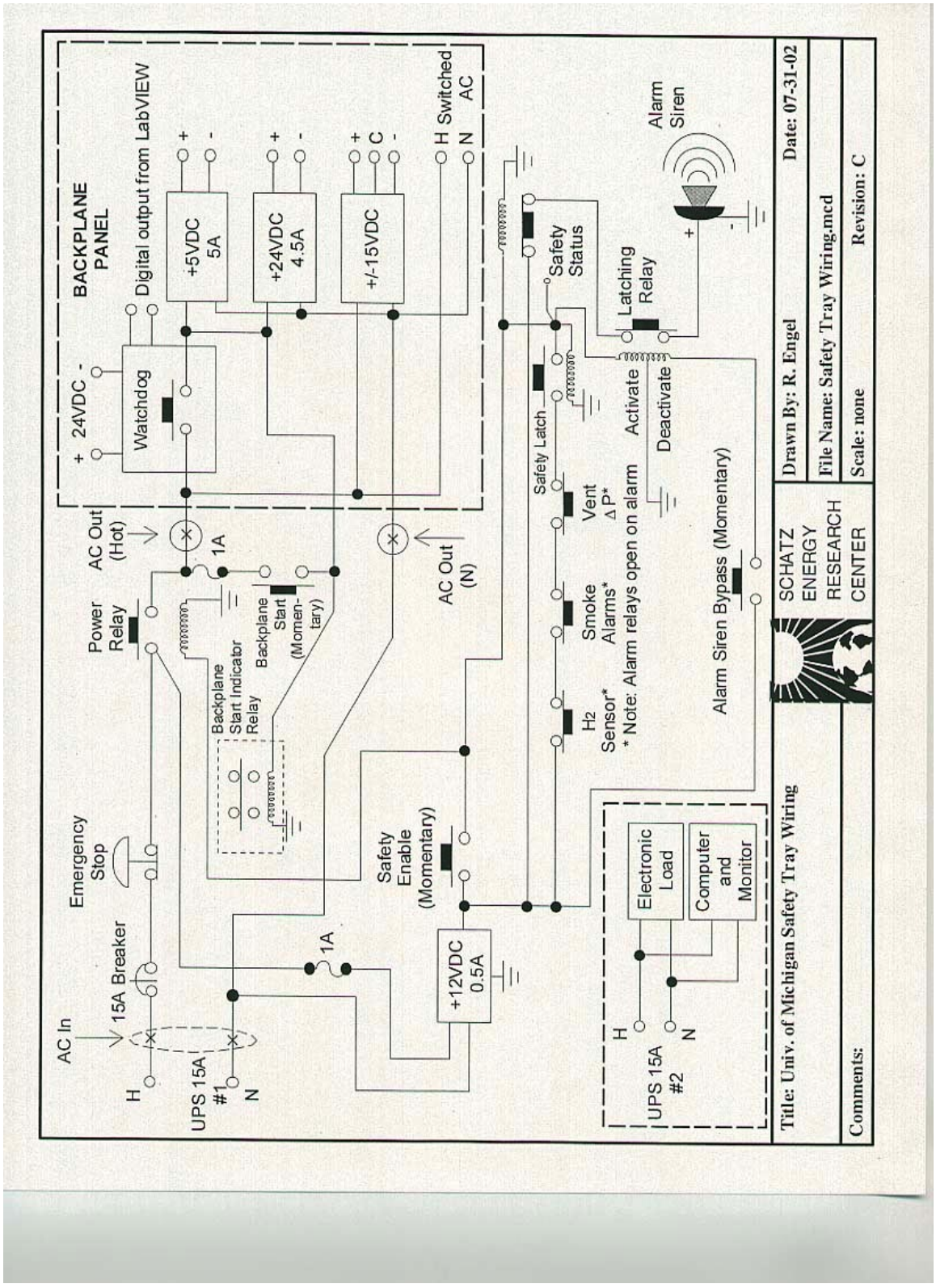
Last modified on 7/16/02 at 4:00 PM
Printed on 8/2/02 at 10:26 AM
Global Variables for the Digital Inputs and Outputs
Port 0 Input
Float Switch 0
Spare 1 1
Spare 2 2
Spare 3 3
Spare 4 4
Spare 5 5
Spare 6 6
Spare 7 7
Port 1 Output
Watchdog 8
Load Contactor 9
H2 Supply 10
MFC Air Supply 11
Reservoir Fill 12
H2 Purge 13
fan 14
Blower Air Supply 15
Port 2 Output
AC Outlet 1 16
AC Outlet 2 17
AC Outlet 3 18
AC Outlet 4 19
AC Outlet 5 20
AC Outlet 6 21
AC Outlet 7 22
AC Outlet 8 23
Port 3 Output
Spare 24 24
Spare 25 25
Spare 26 26
Spare 27 27
Spare 28 28
Spare 29 29
Spare 30 30
Spare 31 31

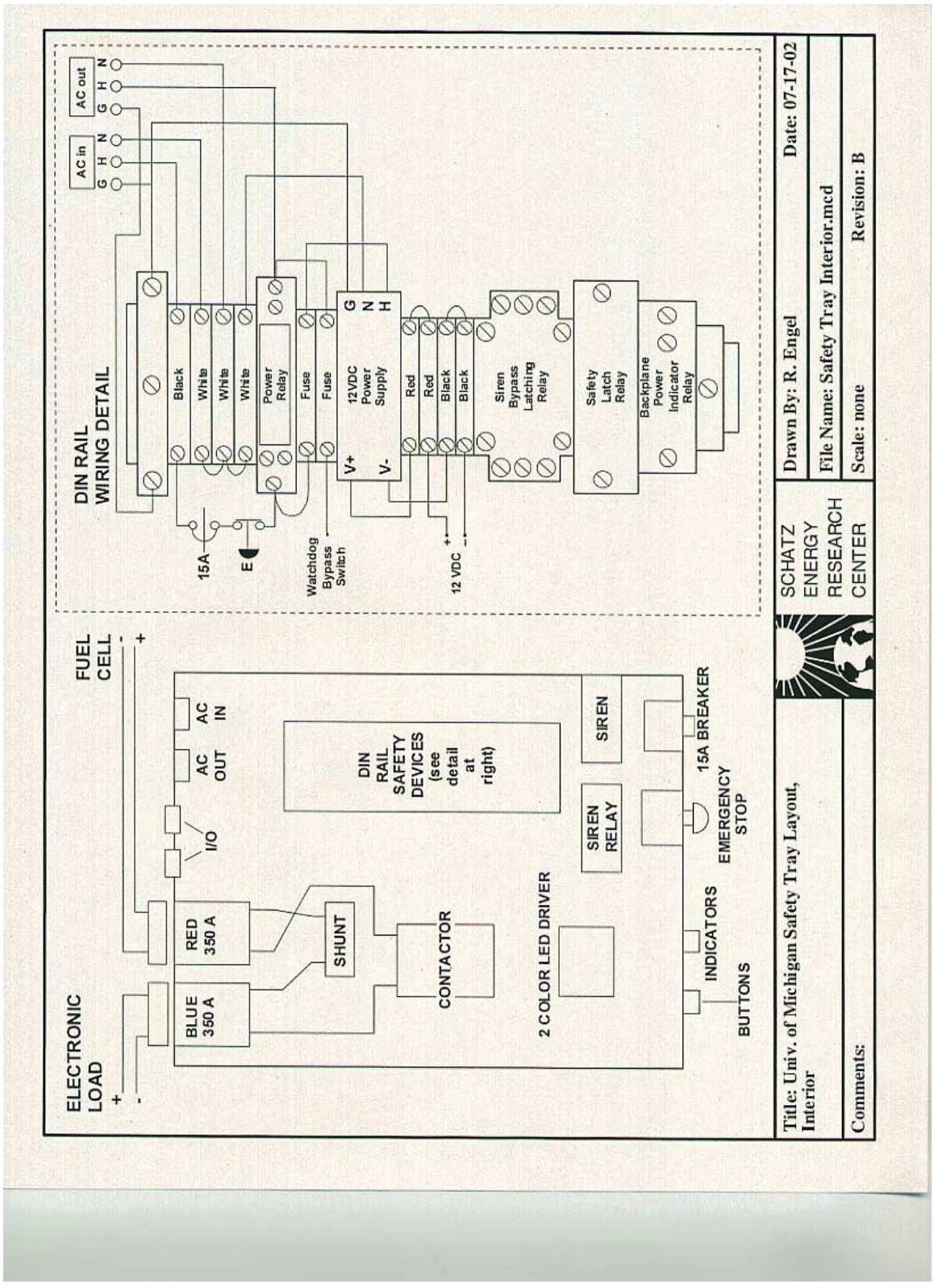

From
Air Compressor
Manual
Valve
Pressure
Regulator
Supply
Solenoid
Valve
PRV
(55 psig setpoint)
0-20 slm
Mass
Flow
Controllers
0-200 slm
Pressure
Gauge
Pressure
Transducer
PRV
(150" H2O setpoint)
Fuel Cell
Air
H_2
Exhaust
Line
SCHATZ
ENERGY
RESEARCH
CENTER
Title: Test Station Air System
Drawn By: G. Chapman
Date: 7-31-02
File Name: Test Station Air System
Scale:
Revision: 3
Comments:

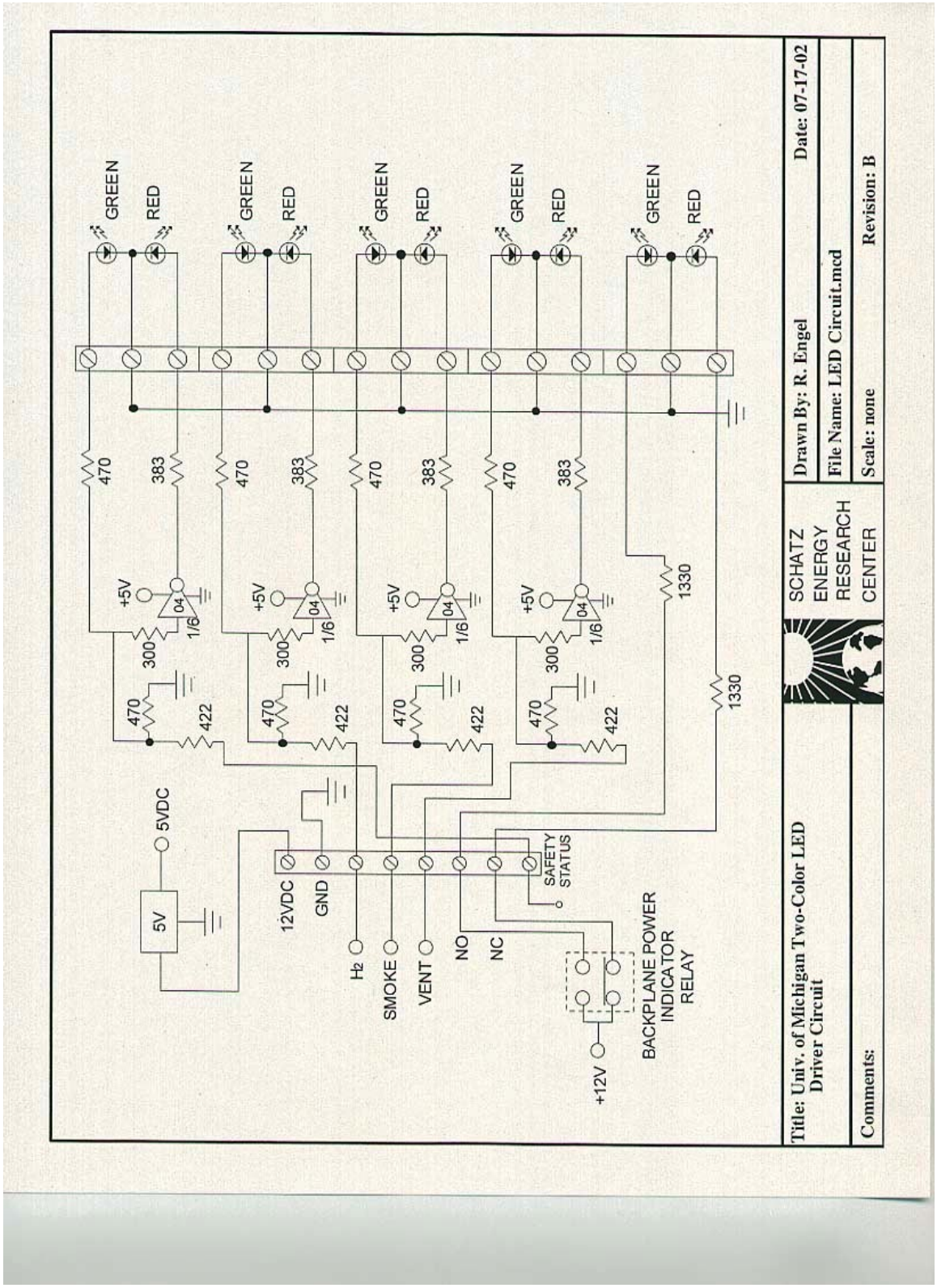

Hydrogen Cylinder
Cylinder Valve
CGA 350 Fitting
Supply Gauge
High Pressure Regulator
Delivery Gauge
Delivery Valve
Flex Hose
Vent Line
Vent Valve
Pressure Relief Valve (150 psig)
Supply Manual Valve
Filter (7 micron)
Low Pressure Regulator with built-in relief valve (9 psig)
Mass Flow Meter (0-100 slm)
Supply Solenoid Valve
Pressure Transducer
Pressure Gauge
Fuel Cell
Air
H_2
Purge Solenoid Valve
Manual Bypass Valve
Purge Drum
Drain Valve
Water drain
SCHATZ ENERGY RESEARCH CENTER
Title: Test Station Hydrogen System
Drawn By: G. Chapman
Date: 9-11-02
File Name: Test Station Hydrogen System
Scale:
Revision: 6
Comments:

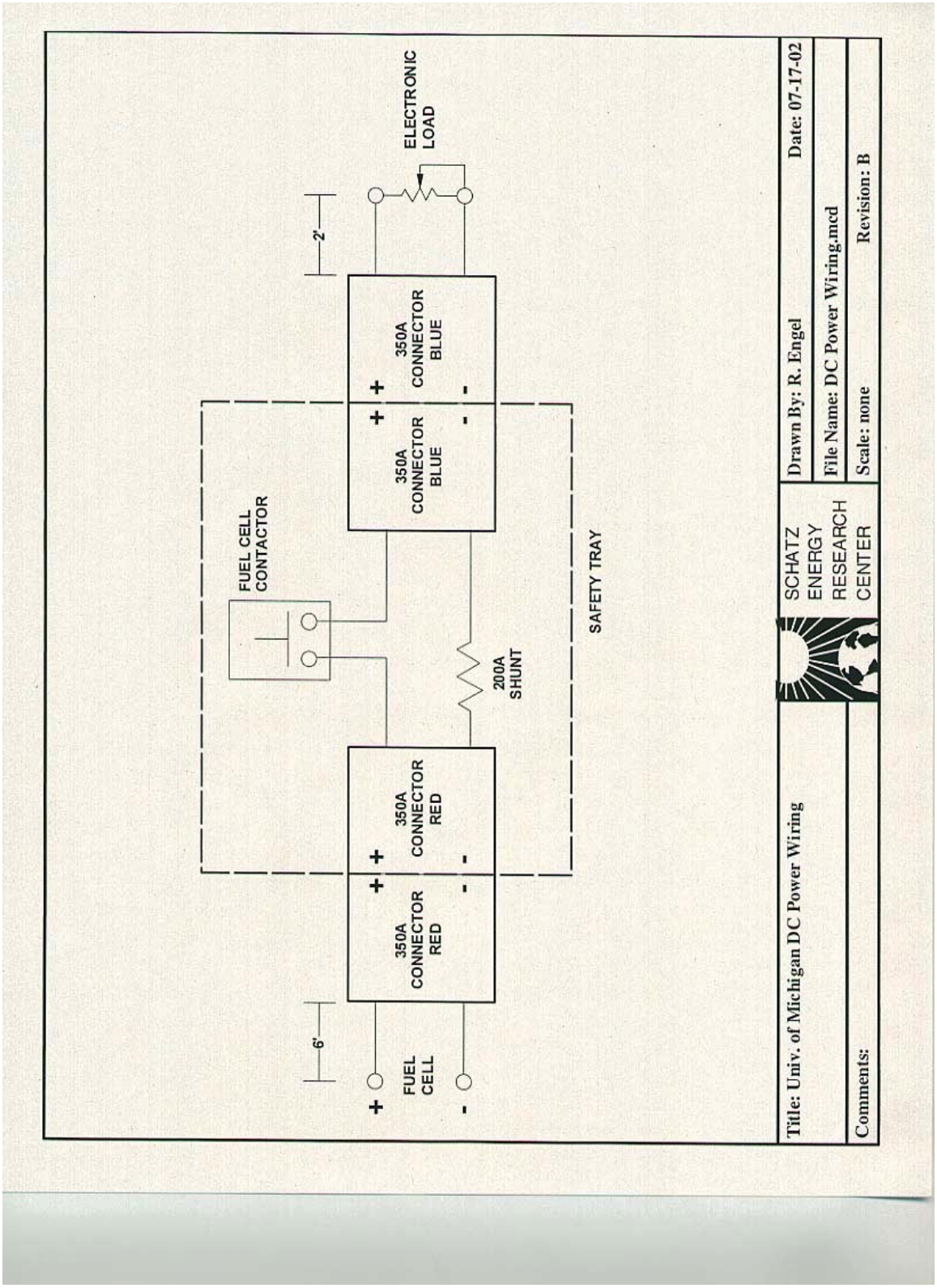

Vent
Reservoir
AC Heater
Overflow Line
From Main DI Line
Fill Solenoid
Fuel Cell
H_2/Air
H_2O
Reservoir Drain Valve
To Drain Line
Circulation Pump
Pressure Relief Valve (120" H2O)
Pressure Gauge
Heating Tape
Conductivity Sensor (0-10 µS)
µS
Throttle Valve
Heat Exchanger
Flow Meter (0.2-5 lpm)
DI Filter
Cooling Fans
SCHATZ ENERGY RESEARCH CENTER
Drawn By: Greg Chapman
Date: 9-11-02
File Name: Test Station Water System
Scale:
Revision: 5
Title: Test Station Water Circulation System
Comments:

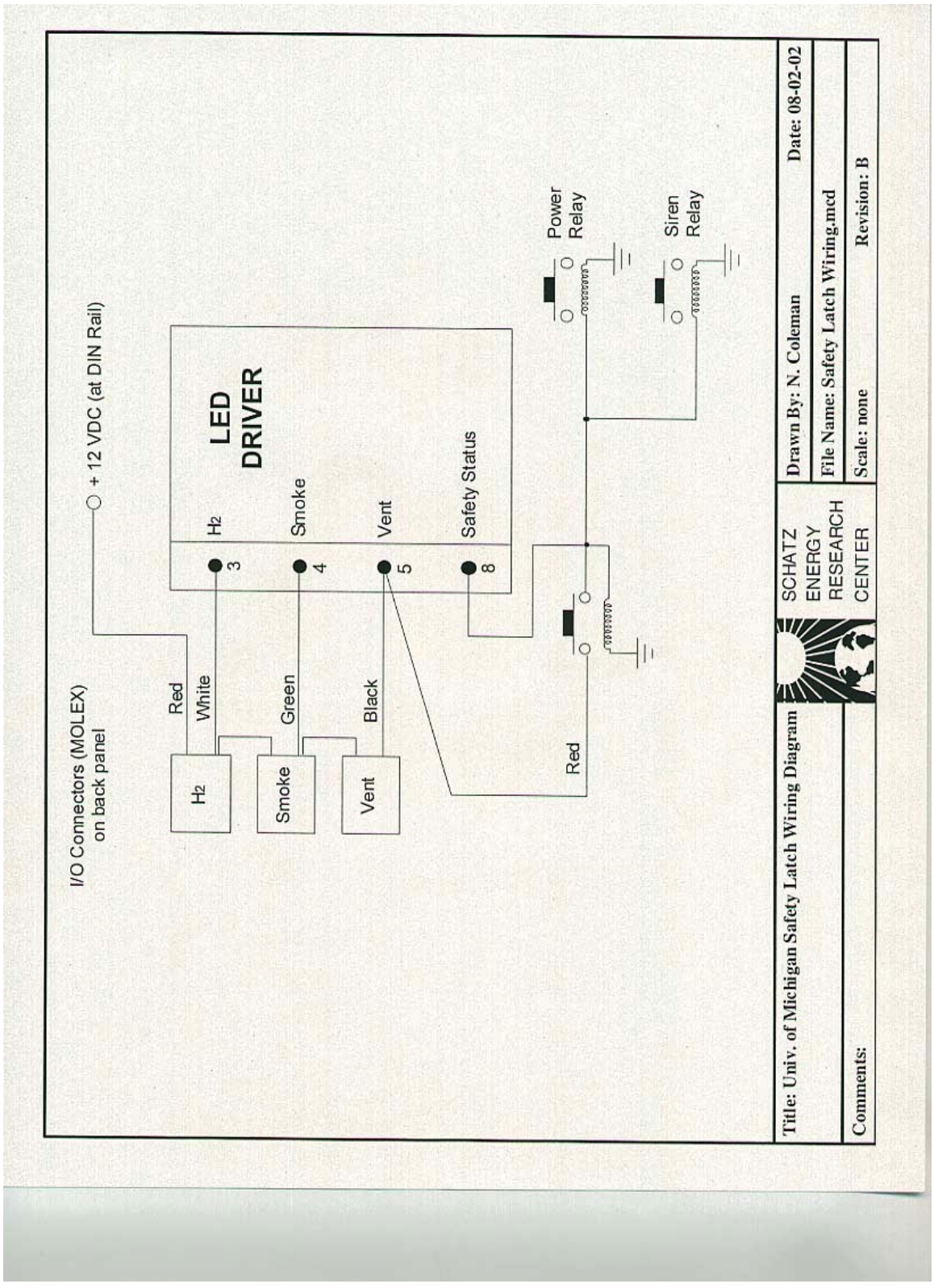
Front Panel
Safety Panel
Backplane Start
Safety Enable
Siren Bypass
Safety Status
H2 Sensor
Smoke Alarm
Vent
Backplane Power
Emergency Stop
ON
OFF
15 A
Back Panel
IN
OUT
120VAC
H2 (DC)
SMOKE (DC)
VENT (DC)
WATCHDOG BYPASS (120VAC!)
FC CONTACTOR
IFC (DC)
FUEL CELL
LOAD
Title: Univ. of Michigan Safety Tray Layout, Front and Back Panels
SCHATZ ENERGY RESEARCH CENTER
Drawn By: R. Engel
Date: 07-17-02
File Name: Safety Tray Front Back.mcd
Comments:
Scale: none
Revision: B

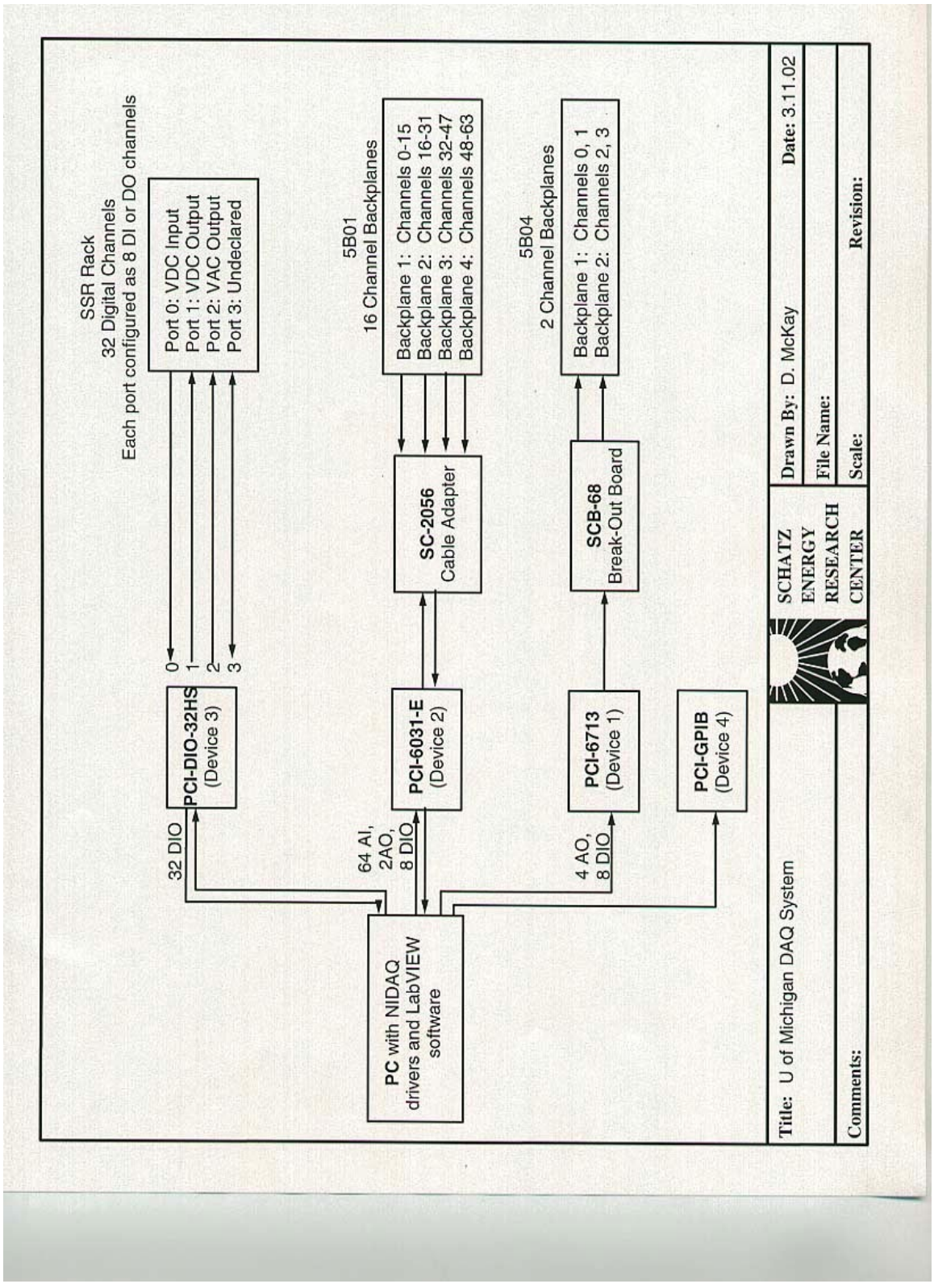

BACKPLANE PANEL
+ 24VDC -
Watchdog
Digital output from LabVIEW
+5VDC 5A
+24VDC 4.5A
+/-15VDC
H Switched
N AC
AC In
15A Breaker
H
UPS 15A #1
N
Emergency Stop
Power Relay
AC Out (Hot)
1A
Backplane Start Indicator Relay
Backplane Start (Momentary)
AC Out (N)
Safety Enable (Momentary)
+12VDC 0.5A
1A
Safety Latch
Safety Status
Vent ΔP*
Smoke Alarms*
H2 Sensor*
* Note: Alarm relays open on alarm
Activate
Deactivate
Latching Relay
Alarm Siren
Alarm Siren Bypass (Momentary)
H
UPS 15A #2
N
Electronic Load
Computer and Monitor
SCHATZ ENERGY RESEARCH CENTER
Drawn By: R. Engel
Date: 07-31-02
File Name: Safety Tray Wiring.mcd
Scale: none
Revision: C
Title: Univ. of Michigan Safety Tray Wiring
Comments:


ELECTRONIC LOAD
FUEL CELL
BLUE 350 A
RED 350 A
SHUNT
I/O
AC OUT
AC IN
CONTACTOR
2 COLOR LED DRIVER
DIN RAIL SAFETY DEVICES (see detail at right)
SIREN RELAY
SIREN
INDICATORS
BUTTONS
EMERGENCY STOP
15A BREAKER
DIN RAIL WIRING DETAIL
AC in
AC out
15A
E
Watchdog Bypass Switch
12 VDC
Black
White
White
White
Power Relay
Fuse
Fuse
12VDC Power Supply
V+
V-
Red
Red
Black
Black
Siren Bypass Latching Relay
Safety Latch Relay
Backplane Power Indicator Relay
SCHATZ ENERGY RESEARCH CENTER
Drawn By: R. Engel
Date: 07-17-02
File Name: Safety Tray Interior.mcd
Scale: none
Revision: B
Title: Univ. of Michigan Safety Tray Layout, Interior
Comments:


GREEN
RED
470
383
+5V
04
1/6
300
422
1330
5VDC
5V
12VDC
GND
H2
SMOKE
VENT
NO
NC
SAFETY STATUS
+12V
BACKPLANE POWER INDICATOR RELAY
SCHATZ ENERGY RESEARCH CENTER
Title: Univ. of Michigan Two-Color LED Driver Circuit
Drawn By: R. Engel
Date: 07-17-02
File Name: LED Circuit.mcd
Scale: none
Revision: B
Comments:


ELECTRONIC LOAD
2'
350A CONNECTOR BLUE
350A CONNECTOR BLUE
FUEL CELL CONTACTOR
SAFETY TRAY
200A SHUNT
350A CONNECTOR RED
350A CONNECTOR RED
6'
FUEL CELL
+
-
Title: Univ. of Michigan DC Power Wiring
SCHATZ ENERGY RESEARCH CENTER
Drawn By: R. Engel
Date: 07-17-02
File Name: DC Power Wiring.mcd
Comments:
Scale: none
Revision: B


I/O Connectors (MOLEX)
on back panel
+ 12 VDC (at DIN Rail)
LED
DRIVER
H2
Smoke
Vent
Safety Status
3
4
5
8
Red
White
Green
Black
H2
Smoke
Vent
Red
Power
Relay
Siren
Relay
Title: Univ. of Michigan Safety Latch Wiring Diagram
SCHATZ
ENERGY
RESEARCH
CENTER
Drawn By: N. Coleman
Date: 08-02-02
File Name: Safety Latch Wiring.mcd
Scale: none
Revision: B
Comments:


SSR Rack
32 Digital Channels
Each port configured as 8 DI or DO channels
Port 0: VDC Input
Port 1: VDC Output
Port 2: VAC Output
Port 3: Undeclared
0
1
2
3
PCI-DIO-32HS
(Device 3)
32 DIO
5B01
16 Channel Backplanes
Backplane 1: Channels 0-15
Backplane 2: Channels 16-31
Backplane 3: Channels 32-47
Backplane 4: Channels 48-63
SC-2056
Cable Adapter
64 AI,
2AO,
8 DIO
PCI-6031-E
(Device 2)
5B04
2 Channel Backplanes
Backplane 1: Channels 0, 1
Backplane 2: Channels 2, 3
SCB-68
Break-Out Board
4 AO,
8 DIO
PCI-6713
(Device 1)
PCI-GPIB
(Device 4)
PC with NIDAQ
drivers and LabVIEW
software
SCHATZ
ENERGY
RESEARCH
CENTER
Drawn By: D. McKay
Date: 3.11.02
File Name:
Scale:
Revision:
Title: U of Michigan DAQ System
Comments:

Appendix B: Component Specification Sheets and Manuals (see Separate Binder)

Components are listed in the order product literature is filed in the Component Binder

Hydrogen System
- Hastings HFM-201 Flowmeter/Controller
- Matheson Tri-Gas 3122-350 High Pressure Regulator
- Matheson Tri-Gas 3702 Low Pressure Regulator
- Omega PX603 Pressure Transducer
- ASCO 8262G208 Solenoid Valve
- ASCO 8210G93 Purge Solenoid Valve
- Swagelok CPA Series Check Valve (Pressure Relief)
- TF Series Tee Type Removable Filter

Air System
- Omega PX4202 Pressure Transducer (Calibration Certificate)
- MKS Type 1179A24CS1BV Mass-Flo® Controller
- MKS Type 1559A-200L-SV Mass-Flo® Controller
- ASCO 8262G230 Solenoid Valve
- Wilkerson B08 Filter/Regulator
- Swagelok SS-4CPA2-DG-50 Check Valve
- Swagelok CA Series Check Valve (Pressure Relief)

Water System
- Pathfinder Conductivity Transmitter Model CT-1000-pt
- Sensorex Conductivity Probe
- Omegalux FGH Flexible Heating Tape
- Omegalux VPT-107/120 Immersion Heater
- March AC-2CP-MD Pump
- ASCO 8262G86 Solenoid Valve
- McMillan 101-8 Flo-Sensor
- Water Filter Changing Instructions
- Swagelok CPA Series Check Valve (Pressure Relief)

Electrical System
- Dynaload RBL488 Electronic Load
- Tripp-Lite SmartPro 3000 Rack Mount UPS

Monitoring and Control Hardware
- National Instruments SSR Modules and Backplanes
- National Instruments SC-2056 Cable Adapter
- PCI 6711/6713 AO DAQ Board
- National Instruments SCB-68 68-Pin Shielded Connector Block, AO Cable Adapter
- 5B03/5B04 Backplanes

Omron S82J Switching Power Supply
Power-One HBB15 1.5A ±15VDC Power Supply
Instrument Pinouts and Color Codes

Safety System

Rack-Mount Tray/Chassis RM14212
ESL 320A/350 Series AC Powered Photoelectric Smoke Alarm
Johnson Controls P32 Series Sensitive Differential Pressure Switch
Bacharach Series 4600 Gas Plus Universal Gas Transmitter
Brentek WDT 24D-5A Watchdog Timer Module
Brentek DIN5 DIN Rail-Mounted I/O Sockets
SafetyGram-4 Gaseous Hydrogen Information

Appendix C: Quick Reference Procedures

Quick Reference Procedures

Start-Up Procedure

1. Turn the UPS on.
2. Turn the Safety Tray POWER switch ON.
3. Press the SAFETY ENABLE button on the tray.
4. Turn on the computer and launch the LabVIEW™ test station program.
5. Connect all subsystem lines, electrical cables, VTaps and thermocouples.
6. Perform a valve line-up on the test station subsystems as follows.
    a. Water Circulation System
        i. Close the water reservoir drain valve.
        ii. Open the DI water supply valves.
        iii. Open the water throttle valve half way.
    b. Air System
        i. Open the air supply valve.
        ii. Position the 3-way valve to the desired MFC.
    c. Hydrogen System
        i. Close the vent valve, supply manual valve, delivery valve, cylinder valve, and purge drum. Back out the regulator.
        ii. Vent back to the cylinder valve.
        iii. Open the cylinder valve.
        iv. Increase pressure to 80 psig using the regulator adjustment.
        v. Open the delivery valve.
        vi. Quickly vent the line.
        vii. Open the supply valve.
7. Start the test station program.
8. Select the stack that will be tested
9. Enter the stack parameters in the dialog box.
10. Change the data file, if desired.
11. Press the BACKPLANE START button, then press the OK button.
12. CLEAR SAFETY FAULT button in software.
13. Enter the desired temperature and reservoir values in the COOLING settings box.
14. Enable the reservoir AUTO FILL to fill the water system.
15. Turn the water pump on and adjust the water throttle valve as necessary.
16. Open the air bleed valve on the right endplate
17. Enable the water heaters or cooling fans depending on desired mode.
18. Enter air source, airflow mode and surge information, then open the AIR SUPPLY and connect the air tubing to the stack.
19. Enter purge control values in the H_2 settings box.
20. Open the H_2 SUPPLY and manually purge by pressing and holding open the PURGE button for a few seconds
21. Select the SAFETY settings box, enter values for the low level faults, and enable the SAFETIES.
22. Once voltages are > the minimum cell voltage safety setpoint, enable the SAFETIES.
23. Turn on the load.
24. Enter the correct range, desired mode and limit type and value information in the LOAD SETTINGS box and press the ENABLE LOAD button.

25. Set the load by entering the desired value into the SETPOINT control box.
26. Verify the system parameters are within their normal range of operation using the table on the back of this page.

Normal Values for Test Station Operating Variables

System	Indication/Parameter	Monitored at	Normal Value/Range
Air	Setpoint stoichiometry	front panel	200-300%
	Actual stoichiometry	front panel	200-400%
	Air inlet pressure	front panel	0-50 in. WC
	Air regulator pressure	gauge	20-35 psig
Hydrogen	Cylinder regulator pressure	gauge	80-100 psig
	Low pressure regulated pressure	front panel	2-5 psig
Water	Water flow rate	front panel	1-4 liters/min.
	Temperature at fuel cell	front panel	Setpoint ± deadband
	Conductivity	front panel	< 5 μS
	Water pressure	gauge	<100 in. WC

Shutdown Procedure

1. Set the load to 0 Amps.
2. Press the PROGRAM SHUTDOWN button.
3. Make sure the BACKPLANE POWER LED is red.
4. Shut off the DynaLoad.
5. Turn the safety tray off.
6. Close the DI water valve.
7. Disconnect the air line from the fuel cell and cap the air inlet fitting.
8. Close the air bleed valve on the right end plate.
9. Close the air supply manual valve.
10. Close the hydrogen supply manual valve.
11. Close the hydrogen cylinder valve.
12. Quickly open the vent valve to depressurize back to the cylinder.
13. Close the delivery valve.
14. Back out the regulator.

DynaLoad range chart is shown at right →

RBL-100-600-4000

OPERATING RANGES (FULL SCALES)

Voltage: 10 Volts, 50 Volts, 100 Volts
Current: 20 Amps, 200 Amps, 600 Amps

OPERATING MODES

Constant Current: 0 to Selected Full Scale Current
* Prog. Accuracy: 600A/200A Ranges: ±0.25%
20A Range: ±0.5%
Regulation: ±0.1% of Full Scale

Constant Resistance: Expressed in Amps/Volt
* Prog. Accuracy: ±3% of Full Scale
Regulation: ±3% of Full Scale

High Ohms Mode

Range	20A	200A	600A
10V	0 - 1 A/V	0 - 10 A/V	0 - 30 A/V
50V	0 - .2 A/V	0 - 2 A/V	0 - 6 A/V
100V	0 - .1 A/V	0 - 1 A/V	0 - 3 A/V

Low Ohms Mode

Range	20A	200A	600A
10V	0 - 10 A/V	0 - 100 A/V	0 - 300A/V
50V	0 - 2 A/V	0 - 20 A/V	0 - 60 A/V
100V	0 - 1 A/V	0 - 10 A/V	0 - 30 A/V

Constant Voltage: 0 to Selected Full Scale
* Prog. Accuracy: 100V/20V Ranges: ±0.25%
10V Range: ± 0.5%
Regulation: ±0.15% of Full Scale

Constant Power: 0 to 4000 Watts
* Prog. Accuracy: ±3% of Full Scale
Regulation: ±3% of Full Scale

Short Circuit: 0.003 Ohms Max.

METERS

	20A	200A	600A
Ammeter Accuracy(±1 Digit):	±0.5%	±0.25%	±0.25%
Ammeter Resolution:	10mA	100mA	1A
	10V	50V	100V
Voltmeter Accuracy(±1 Digit):	±0.5%	±0.25%	±0.25%
Voltmeter Resolution:	10mV	100mV	100mV

Appendix D: Material Safety Data Sheet